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INFRARED THERMOGRAPHY OF BUILDINGS: 1977 COAST GUARD SURVEY.(U)
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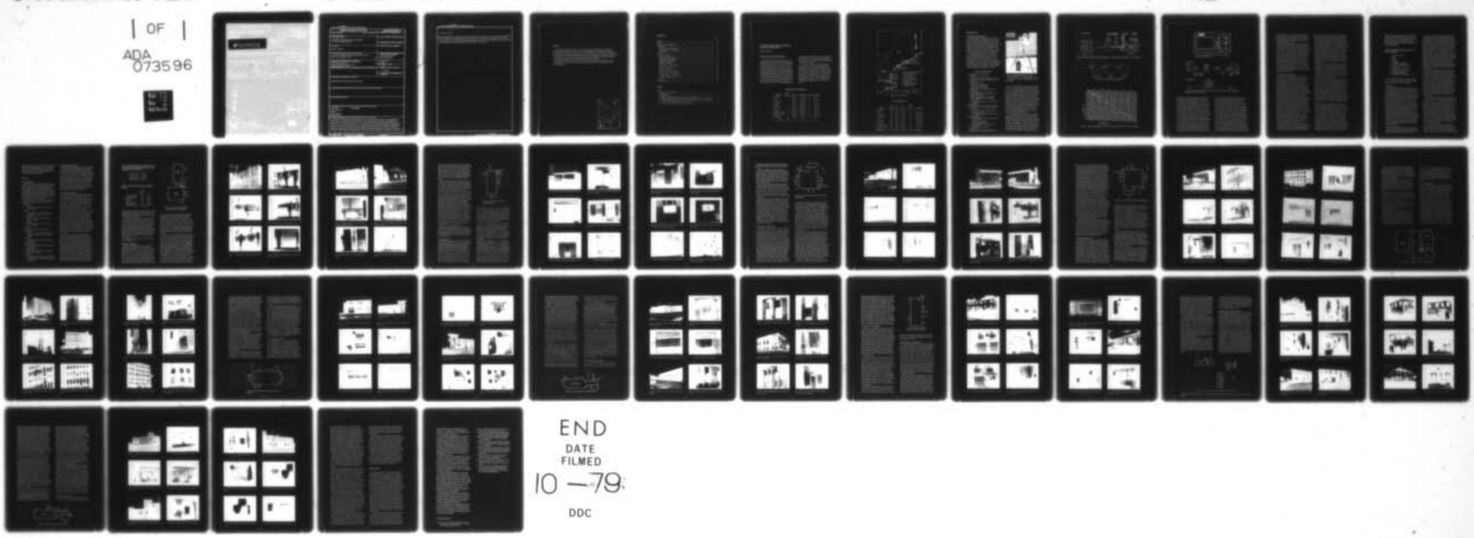

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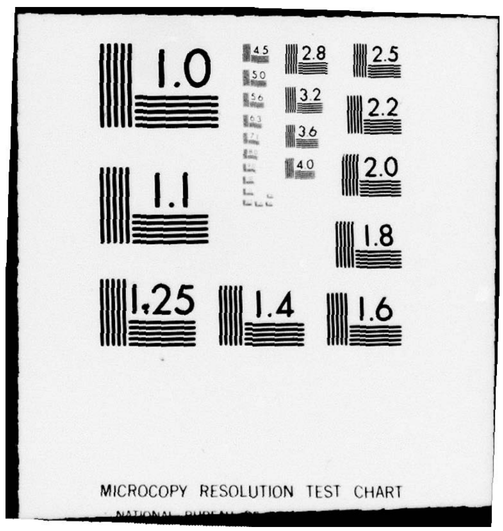
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An IRTB (infrared thermography of buildings) field survey, producing 631 thermograms, 127 photographs, and weather data, was conducted during a 14-day study of 10 Coast Guard stations in Maine, New Hampshire and Massachusetts. This report discusses how the survey was initiated and performed with emphasis on details for the benefit of the reader wishing to plan a survey. One-hundred and twenty selected thermograms and photographs in this report illustrate many types of heat loss and compare thermally ineffective doors and windows with units designated as standards for thermal effectiveness. Radiator heat leakage through walls, mottled moisture patterns on brick walls, infiltration patterns on glass, and poorly covered openings are illustrated. Thermograms of severe heat

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losses through glass doors, glass transoms, and glass wall panels are also included, and several solutions for individual heat loss problems, such as fiberglass garage doors and porcelain insulated panels, are suggested. Unanticipated survey problems, such as difficulties in obtaining photographs to compare with thermographically discovered artifacts and adjustments to survey techniques for inclement weather, are also discussed.

PREFACE

This report was prepared by Stephen J. Marshall, Physical Science Technician, of the Physical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the U.S. Department of Transportation, U.S. Coast Guard, First District under Project MIPR 7LB731C0206, *Thermographic Inspection of 26 Buildings at 10 Coast Guard Facilities.*

This report was technically reviewed by Roger Berger and Harold O'Brien of CRREL. Technical assistance during the survey was provided by Dr. Richard Munis of CRREL.

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INFRARED THERMOGRAPHY OF BUILDINGS: 1977 COAST GUARD SURVEY

Stephen J. Marshall

INTRODUCTION AND BACKGROUND

Following the 1973 energy crisis, the U.S. Coast Guard became particularly concerned about reducing the energy consumption of its more than 600 widely scattered shore units, which were found to account for 40% of the total energy consumed.[2] Among the solutions investigated by Coast Guard civil engineers was the recent development of infrared thermography of buildings (IRTB), and with CRREL's assistance, a complete ground-level infrared survey was conducted at the Coast Guard Academy, New London, Connecticut[7] in 1976. It was discovered from this survey that, with careful planning, a great deal of information about the thermal efficiency of buildings and systems can be obtained in a short time with thermography. A Civil Engineering Technical Report was prepared and distributed to all Coast Guard Civil Engineering Offices and Public Works Officers.[1]

In January 1977 the First Coast Guard District chose 10 stations in Maine, New Hampshire, and Massachusetts for a themographic imaging survey.[9] CRREL personnel were chosen to conduct the survey due to their early experience in developing practical applications of the IRTB concept.[5] The survey of the 10 stations was conducted from 6-13 April 1977, resulting in the production of 631 thermograms, 127 photographs and support data[3] (see Tables I and II). The locations of the survey sites are indicated in Figure 1.

Table I. Basic survey information.

Station	*No. of bldgs.*	*Date*	*Thermograms*	*Total*	*Photographs*
1. Marshfield	1	6 Apr 77	1 to 68	68	1 to 9
2. Hull	1	6,7 Apr 77	69 to 128	59	10 to 19
3. Newburyport	1	7 Apr 77	129 to 163	34	20 to 26
4. Gloucester	1	7 Apr 77	164 to 215	51	27 to 35
5. Boston	5	8 Apr 77	216 to 280	64	108 to 127
6. New Castle	3	9 Apr 77	281 to 343	62	36 to 51
7. Portland	4	10 Apr 77	344 to 419	75	52 to 67
8. Boothbay Harbor	2	11 Apr 77	420 to 473	53	68 to 77
9. Southwest Harbor	5	12 Apr 77	474 to 554	80	78 to 94
10. Jonesport	3	13 Apr 77	555 to 631	76	95 to 107
Total	26				

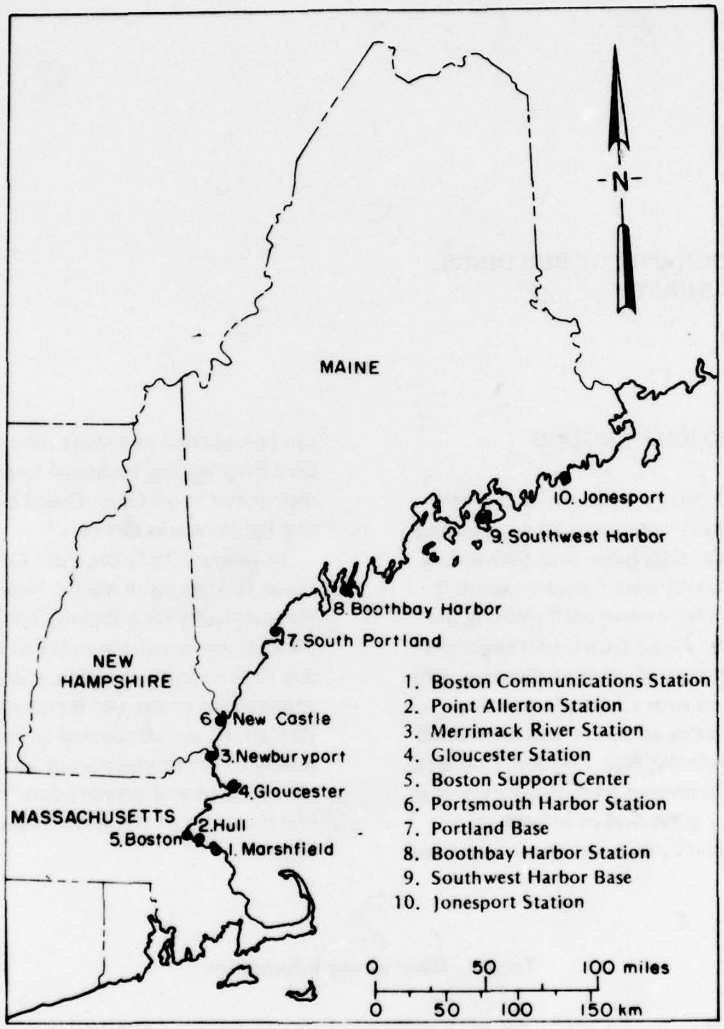

Figure 1. Survey sites map.

Table II. Weather data.

Station	*Begin survey*	*End survey*	*Survey time*	*Outside temperature (°C)*	*Windspeed*
1. Marshfield	1910	2159	2 H 49 M	6.1	
2. Hull	2355	0138	1 H 43 M	2.2	20 knots W
3. Newburyport	1840	2010	1 H 30 M	4.4	2 knots SW
4. Gloucester	2215	2358	1 H 43 M	1.1	18 knots SSW
5. Boston	2030	2240	2 H 10 M	−1.1	15 knots 227°
6. New Castle	1945	2146	2 H 1 M	1.7	3 knots 225°
7. Portland	2027	2225	1 H 58 M	2.2	17 knots NNW
8. Boothbay Harbor	1935	2211	2 H 36 M	4.4	12 knots SW
9. Southwest Harbor	2055	0028	3 H 33 M	5.6	Calm
10. Jonesport	1955	2222	2 H 27 M	5.6	5 knots E

METHODOLOGY

Description of camera operation

A infrared thermal imaging system is a category of radiometer that converts an infrared image to a visual image. It detects infrared amplitude variations over a rectangular field of view and represents them as discrete density variations from dark gray to bright white on a cathode ray tube (CRT). It is analogous to a combination of a television camera which takes the video pictures and a television receiver which displays them.

Thermal imaging systems are usually sensitive to two wavelength bands or windows in the infrared portion of the electromagnetic spectrum: 2-5.6 μm (midwave) and 8-14 μm. These two bands are frequently called "windows" because of the high degree of transparency of the atmosphere in these wavelengths. The basic parameters of the portable infrared imaging system used in this survey are listed in Table III, and the basic components are illustrated in Figure 2.

Table III. Equipment used.

A. AGA Model 750 Thermovision System
  1. Imaging unit
    Detector: indium antimonide (InSb)
    Spectral range: 2-5.6 μm (low sensitivity below 3 μm)
    Coolant: liquid nitrogen, 2 hours between refills
  2. Display unit
    Picture size: 50×45 mm
    Field frequency: 25 per second
    Line frequency: 2500 per second
    Lines per frame: 280 (interlaced)
    Resolving power: 100 picture elements per line
  3. Specifications
    Power requirements: 8-15 V DC, 21 W
    Operating temperature range: −15°C to +55°C
    Weight: 15.68 kg total
    Object temperature range: −20°C to +900°C
    Minimum detectable temperature differences: 0.2°C @ 30°C
    Instantaneous field-of-view: 3.4 mrad (0.2° @ 50% contrast)

B. System accessories
  1. Batteries (two): 12-V nickel-cadmium rechargeable
  2. Lens (infrared): 20° x 20° field of view, 33 mm, f/1.8-22
  3. Camera unit: Polaroid, maximum aperture f/8; shutter speed: 1/15 s
  4. Dewar: liquid nitrogen, Union Carbide Corp., type UC-4, capacity: 4.5 kg

C. Survey accessories
  1. Film: Polaroid Type 667 coaterless black and white film, ASA 3000
    Resolution: 16 lines/mm
    Gray scale (perceived shades): 13
  2. Camera: photographic, Polaroid-Land Camera, Automatic 100
  3. Tape recorder: Lanier Model MS-60
  4. Compass: Silva
  5. Thermometer: Syscon International Model 1F

Figure 2. Portable thermal scanner system. 1 – Polaroid camera; 2 – display console; 3 – camera and lens; 4 – tripod; 5 – liquid nitrogen bottle; 6 – battery.

Figure 3 is a schematic of a typical thermal imaging system. The invisible infrared radiation from the area of interest is focused through the special infrared lens onto a rotating prism. The lens is made of silicon which attenuates wavelengths below 2 μm. Figure 4 illustrates how the rotating horizontal prism scans from left to right. The prism is electronically syncronized with the cathode ray tube beam, and Figure 5 illustrates how this scanning interlace pattern moves across the face of the cathode ray tube. As the scanning mechanism sweeps horizontally across the surface being scanned, the lines are progressively stepped down to cover the entire surface. The scanning mechanism moves very rapidly, making 25 complete frames each second. Each frame consists of 280 horizontal scan lines.

The incoming infrared radiation is then collimated and focused on the surface of an indium-antimonide (InSb) detector which converts the impinging midwave infrared amplitude variations into electronic amplitude variations. The detector is housed in a Dewar flask and is cooled by liquid nitrogen (−196°C) which increases its sensitivity and stability. The electronic signals from the infrared detector are amplified, processed, and then transmitted to the cathode ray tube where they are converted to a visible image on the fluorescent screen

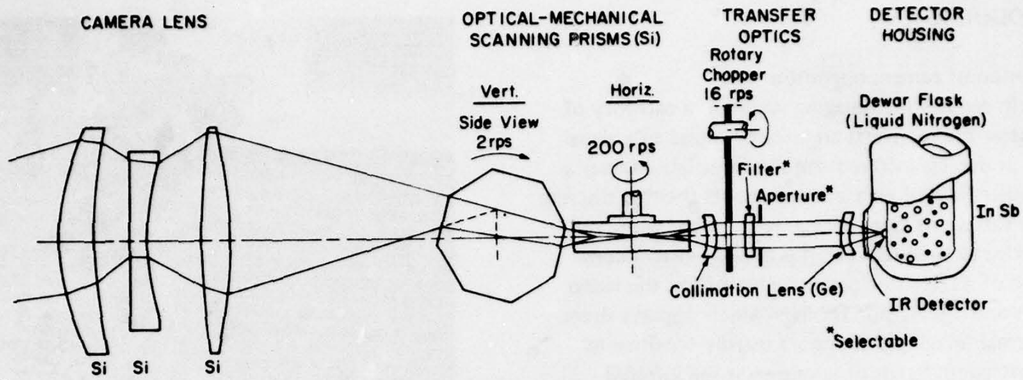

Figure 3. Schematic of a typical thermal imaging system. (Reprinted by permission of AGA Corporation.)

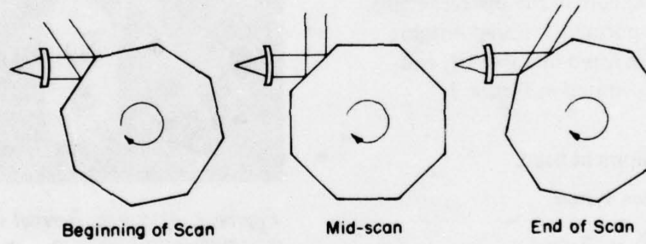

Figure 4. Optical-mechanical scanning prism.

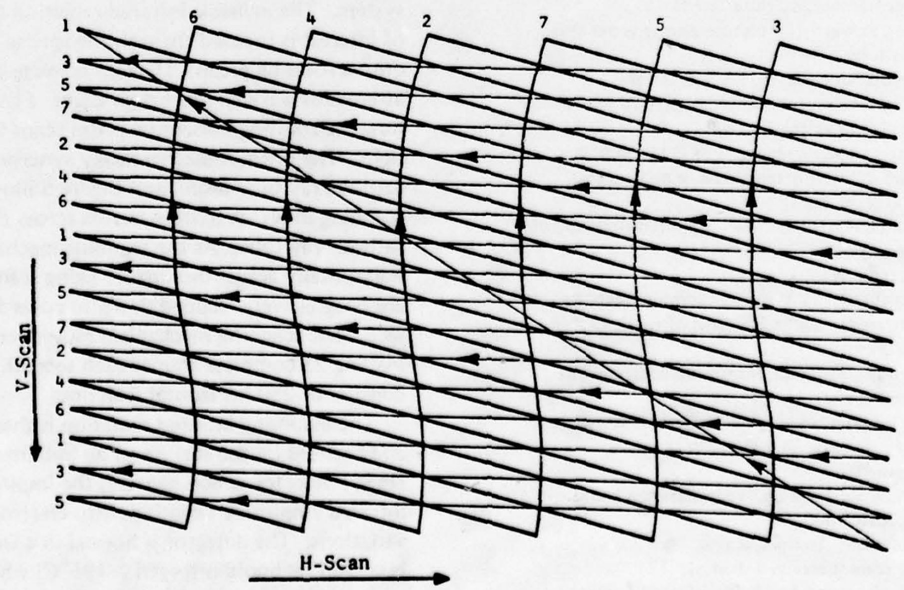

Figure 5. Camera scanning interlace pattern. (Reprinted by permission of AGA Corporation.)

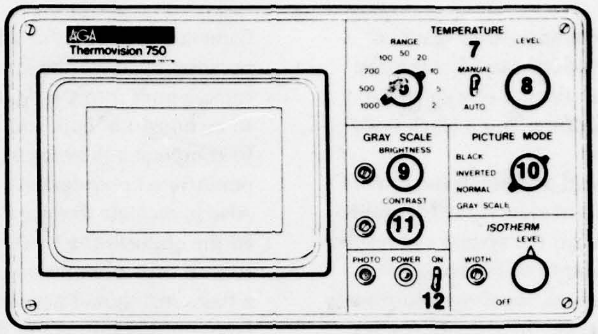

Figure 6. AGA Model 750 console showing CRT display on left and controls on right.

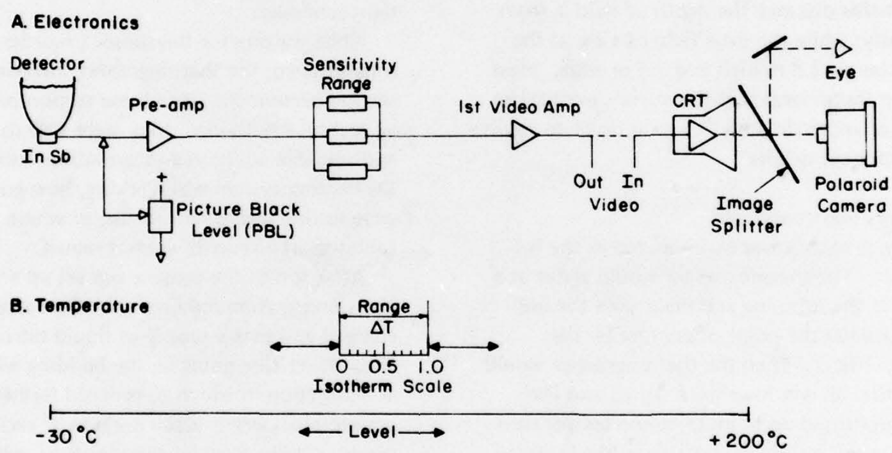

Figure 7. Schematic and illustration of range and level control operation. (Reprinted by permission of AGA Corporation.)

of the CRT. The intensity of the light on the screen of the monitor is representative of the magnitude of the invisible infrared thermal signal being received at that instant by the infrared detector. Thus, real-time, visible images of the area being scanned by the infrared camera, representing the thermal image of this area, are projected on the screen of the monitor. This visible image is photographed to record the thermal pattern in the form of a hard copy thermogram. Figure 6 illustrates the monitor and controls. Figure 7 illustrates the camera's range and intensity control operation.

For thermography of buildings the largest aperture of *f*/1.8 is chosen, which gives an overall potential range of thermal response from –30°C to +200°C. The intensity control is then rotated up or down along this overall range until the image comes in sharply on the screen, usually at a setting near the ambient temperature of the target. Then the operating range or sensitivity position is chosen which will encompass only the portion of the overall range from the lowest to the highest temperature difference (ΔT) on the target. For thermography of buildings, the 2°, 5°, 10°, or 20°C ΔT ranges have been found most satisfactory, depending upon the extremes of heat loss within a particular field of view of the scanner. These temperature ranges affect the intensity of the thermographic image, and they can be selected by the thermographer for varying conditions. The camera displays these ranges with a scale light that appears in the upper left of the thermogram (2, 5, 10 or 20). Smaller temperature differences within the ΔT range can be measured by the use of the camera's isotherm function. This function superimposes brightened isotherm contours on the thermal images of objects. The isotherm contours identify areas of equal temperature (equal tones of gray) in the picture and a vertical marker moves up and down a left-hand picture scale as the isotherm control is adjusted. The 10 divisions of this scale represent

fractions between 0-1 of the temperatures spanned within the picture. These fractions can be converted to absolute temperatures with the use of a calibration chart supplied by the manufacturer and a black body temperature reference source.

Since the instantaneous field-of-view of the camera for the normal $20^\circ \times 20^\circ$ field-of-view lens (33 mm) is 3.4 mrad (0.2°) at 50% contrast, the system can resolve a 6.8-cm spot at 20 m. The depth of field at 20 m is from 3 m to ∞ at $f/1.8$; therefore, focusing adjustments are not critical at these distances. In order to resolve a 2.54-cm wide building component such as a window mullion, the camera will have to be no farther than 7.5 m away. Since many building thermograms are taken at distances of about 7.5 m, it might be mentioned that at this distance the depth of field is from 20 m to infinity, while the total field of view at the target is a rectangle 2.8 m high and 2.5 m wide. Most of the closeup thermograms in this survey were taken at a distance of approximately 7.5 m in order to resolve building component details.

How the survey was conducted

The survey at each site was conducted in the following manner. The thermographer would arrive at a given station in the morning and meet with the individual designated as the point of contact by the Commanding Officer. Then the thermographer would check to see that all windows were closed and the heating system turned up to increase the temperature difference between inside and outside of the building. The charging of the scanner's batteries would be initiated using the station's power, and the thermographer would conduct a walk-through survey which consisted of entering all the facts about the building told to the thermographer or observed by him into a portable tape recorder. This survey served to orient and familiarize the thermographer with the building's floor plan and the locations of obvious heat sources such as radiators, boiler rooms, etc. The thermographer also noted variations from blueprints, such as retrofits, structural changes, etc. All difficulties and complaints about the building -- such as rooms that were too hot or too cold, leaks that developed when it rained, etc. -- were identified in order to locate these problem areas at night during the thermographic survey. Blueprints were consulted in order to determine building orientations, wall materials, types of windows and doors, amounts of insulation, and other factors.

The entire outside of the building was then photographed and closeup shots of areas that the walk-through survey indicated would be noticed thermographically were also taken. A Polaroid-Land Automatic 100 Camera was chosen for all conventional photography because it can use the same type of film as the Polaroid camera built into the AGA System, allowing the film to be bought in bulk and assuring an adequate supply to complete a thermographic survey in the field, since noninfrared photography could be sacrificed if necessary. Also immediate development of the photographs allowed the opportunity to correct poorly exposed shots or to vary their orientation or perspective. In retrospect, a flash unit should have been used to record inside artifacts and to photograph shadowed wall faces. Also more time should have been allowed for photography of artifacts. Many unknown artifacts were discovered by the infrared survey which required followup photography, but this was not done due to the preplanned tight schedule.

While waiting for the sunset (in order to eliminate solar effects), the thermographer interviewed individual station personnel. Since these station personnel were all technically trained, they were able to give correct and valuable additional information, such as how well the heating system was working, how good the windows were during severe rainstorms, or where the electrical cables short-circuited when it rained.

After sunset the camera was set up and tested. Previous preparation required that the batteries be fully charged and that a supply of liquid nitrogen be available. A starting point on the building was chosen as well as a direction in which to proceed (either clockwise or counterclockwise). Each portion of each face was systematically scanned and recorded, whether or not anything unusual showed up, in order to have reference data for thermogram interpretation. Previous surveys, in order to save time and money, tended to record only thermal anomalies, so that little opportunity was afforded to compare poorly insulated areas with better ones. Of course, any anomaly noticed was studied in greater detail.

Each thermogram was consecutively numbered immediately after being taken to assure no chance of mixup, and important information was written on the back of the photograph while waiting for it to develop (see Table IV). This information included: date, station, time, building, orientation of particular face, section of the particular face, and a brief description of any anomaly noted. In addition, other factors such as camera malfunctions or changes in temperature, speed and direction of wind, and camera settings were occasionally noted. Then the covering of the Polaroid photograph was pealed and the photograph was checked with the image on the CRT to see if it was satisfactory. The thermograms were laid out on a flat surface such as a billiard table (if available) in order to dry. This

gave the thermographer the opportunity to compare them with each other and with the latest ones being taken. In this way he could note anomalies inadvertently missed, discover new relationships between building faces, and observe possible malfunction of the camera's performance.

Table IV. Outline for recording necessary facts on back of thermograms.

1. Thermogram number
2. Date
3. Time
4. Location
5. Building
6. Orientation of particular face
7. Section of the particular face
8. Brief description of anomaly noted
9. Comments
10. Temperature: inside and outside
11. Speed and direction of wind
12. Infrared camera settings
13. Photographic camera settings

Finally, the last order of business before finishing was to run down both batteries completely and place them on recharge for the rest of the night.

Problem areas

It was found that the infrared system itself performed adequately with no serious malfunctions other than occasional dark horizontal lines in the screen and the loss of illumination for the ΔT 2°C scale light. A weak double image on the thermograms due to previous breakage and replacement of the fragile image splitter (Fig. 7) was corrected by setting the Polaroid camera that recorded the thermograms at $f/1.8$ with a 1/15-s shutter speed. This camera, however, caused serious problems which significantly slowed down the survey. It jammed frequently causing the rest of the film pack to be thrown away and another pack inserted. This problem was minimized by keeping the carton of coaterless film* in a warm room, faithfully cleaning the stainless steel rollers after each film pack was used, and frequently removing the camera head and taking it inside to warm up for a few minutes. The AGA system itself could be left out in the cold with no apparent harm. The system was turned off in order to conserve crucial battery power whenever the Polaroid camera was being attended to.

It was found that even during a slight drizzle the white paper tabs in the film packs would get soft and tear loose from the film cartridge. The only solution to this problem was to plan all eight shots of a film pack in advance, run out to the already operating infrared system with the camera under a coat and take the photographs in rapid succession. In this way one could get most of a film pack before the tabs began to tear. The numbers on the back of the film were used to keep thermograms in order. The necessary information was quickly written on the back of each before it was forgotten, and this was double-checked against the camera's CRT image to assure that no mistakes were made. Rain does not affect the infrared imagery itself because IR attenuation through rain at such close distances is negligible. The vertical building walls did not seem to get wet enough to change their heat loss characteristics during any of the slight rains encountered during this particular survey.

Another minor problem was caused by obstacles such as boats and equipment that prevented a good thermographic shot of particular areas of a building. Also, a few of the building walls were close to and facing the water or private property, affording no place to position the camera. Shrubbery and parked cars also created some obstacles. Nonetheless an outside survey still proved to be faster and more complete than an inside survey because the inside survey disturbed numerous occupants at night and necessitated moving furniture to obtain clear shots of the walls. Also, in many cases, internal partitions were found to seriously hinder proper placement and orientation choices for locating the system in order to get the best or even satisfactory shots.

It was found that several stations varied from what was actually stated in the specifications for the survey. The term "brick ext." in the specifications was thought to mean brick exterior but actually meant brick extension, i.e. the one-story mess deck extensions on the buildings. Fortunately, surveying these did not involve much more time than had been anticipated. At one station a separately listed electronics shop did not exist but two other buildings of nearly identical size did. The thermographer chose to do both these buildings rather than waste the opportunity. Several of the boathouses were found to be heated or partially heated but none were required to be surveyed in the specifications. The thermographer surveyed one to help the Coast Guard with future planning.

A large old machine shop at one of the stations wasn't listed but was consuming as much heat as all the other buildings combined, according to the station engineer. However, there was not enough scheduled time to take more than a brief look at it. Several of the stations

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* Polaroid type 667 "coaterless" film does not require a protective fluid to be applied, as is necessary with Polaroid type 107 film. Prints from coaterless film dry more quickly, do not scratch or fade, and can be stacked on top of each other.

had heated motor pool and reserve unit buildings, which could have been specified but were not. Finally, the roofs of many of the buildings had serious problems, and a future infrared survey could help detect roof moisture and membrane problems.

RESULTS

Format and theme

A format was chosen for this report that presents a total of 12 thermograms and photographs for each of the 10 stations, giving a total of 88 thermograms and 32 photographs. It was decided to concentrate on thermography of block and brick masonry construction since it was felt that enough literature existed concerning themography of wood frame construction.[4] Therefore, the results of the survey of several wood frame buildings are not included in this report.

The weather data for each station are included in Table II. Each station presents a differing theme, as listed below:

1. Marshfield
   Thermography of moisture in split-ribbed masonry blocks.
2. Hull
   Thermography of wooden window panels and insulated stacked concrete blocks.
3. Newburyport
   Effects of sunlight on thermography of masonry buildings.
4. Gloucester
   Thermography of windows and doors subject to hard usage.
5. Boston
   Thermography of old brick buildings.
6. New Castle
   Effects of orientation and weather on thermography of a single zone heated masonry building.
7. Portland
   Thermography of porcelain insulated panel construction.
8. Boothbay Harbor
   Thermography of heat leakage from radiators under windows.
9. Southwest Harbor
   Comparison of two similar brick buildings and one wood building.
10. Jonesport
    Thermography of a six-zone masonry building with architectural energy conservation design inadequacies.

Selected qualitative standards

Three building components were chosen as standards of comparison because thermograms showed them to be vastly superior in terms of energy conservation to all of the other similar building components examined in this survey. The first (a door at the Boothbay Harbor Station) was found to give better performance because of lack of usage and the other two (an overhead garage door at New Hampshire Department of Public Works and Highways garage[8] and a window at the Portland Support Station) appeared to be of superior design. These standards gave the thermographer an opportunity to make a qualitative judgment for comparison with thermograms of other similar components.

Thermogram interpretation

Site plans for each of the 10 buildings are provided with thermograms and photographs correctly located by numbered arrows on each in order to assist the reader. This was found to be a helpful technique when thermograms were shown to station personnel during the survey. Most personnel had no trouble understanding what was in the thermograms, but some did tend to get disoriented when trying to match thermograms with actual locations on the building.

All the thermograms in this survey were taken in the normal mode of operation; therefore, warmer temperatures appear whiter and colder temperatures appear darker in the thermogram. The scale settings used varied from scale 2 to scale 20. Table V is a rough guide for judging the severity of a particular heat loss situation in terms of the scale selected for recording the artifact noted. The table is useful over the inside/outside ΔT range of 17° to 22°C experienced in the survey. The tendency was to use scales 2 and 5 on areas of the buildings that had no noticeable heat losses, 5 and 10 where irregularities were noticed, and 20 in the most severe cases.

As can be seen in the following thermograms, apparent temperature differences caused by different materials with differing emissivities (Table VI) will appear on the CRT as the exact shape and outline of the particular materials involved, such as glass window panes, wooden window frames, and concrete blocks. These apparent temperature differences are not to be confused with actual heat loss situations which are recognizable by either their white irregular shapes that encompass portions of areas of adjacent differing materials, or by unreasonable variations in intensity on or along a single material. The warm air escaping from interfaces such as the glass/frame/wall interfaces of a window unit exemplifies the first situation, and the warm areas on the face of a masonry wall under each

Table V. Qualitative judgment as to severity of a heat loss situation for masonry buildings surveyed from the outside with a ΔT of 17° to 22°C.

Scale 2 (2°C ΔT)	Mild
Scale 5 (5°C ΔT)	Average
Scale 10 (10°C ΔT)	Excessive
Scale 20 (20°C ΔT)	Severe

Table VI. Emissivities of typical masonry building materials.

	Temperature (°C)	ϵ
Aluminum, anodized	100	0.55
Brick, common red	20	0.93
Concrete	20	0.92
Paint, oil	100	0.94
Glass, polished plate	20	0.94
Wood, planed oak	20	0.90

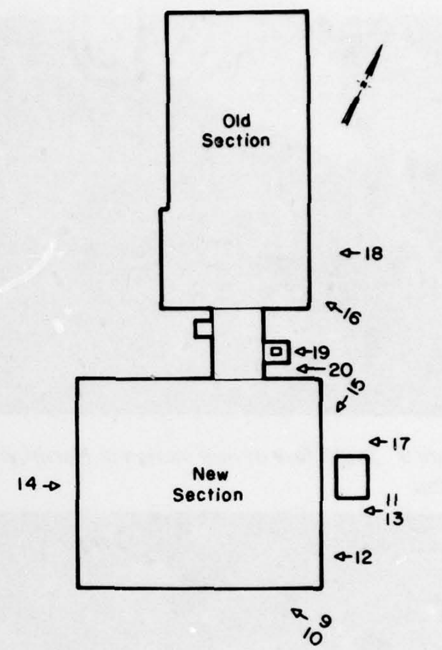

Figure 8. Boston Communications Station, Marshfield, Massachusetts.

window location and directly opposite each room heater illustrate the second situation. In other words, the thermographer must be alert to unreasonable variations in either shape and/or intensity.

Thermogram interpretation is an acquired skill that can be learned only be performing actual surveys in the field and slowly building up a repertoire of experience that can be applied to new and varying situations. The thermographer who actually takes the thermograms is in the best position to interpret them since only he can be aware of all the intricacies that occurred during the survey. Interpretation consumes by far the most time of a complete survey while the actual thermography takes comparatively little time, as can be seen in Table II.

The results of the survey at each of the 10 survey sites are listed below.

Marshfield: Figures 8-20

The Boston Communication Station (Fig. 8) in Marshfield, Massachusetts, consists of a 20-×9-m single-deck old section built of concrete block in 1942, and a two-deck 17- × 14-m new section built of split ribbed block in 1972. Figure 9 is a photograph of the south face of the new section taken from the southeast corner. The face is of split-ribbed masonry blocks stacked vertically in line with poured insulation and waterproofing. Figure 10 shows a thermogram of this face taken from the same perspective. The horizontal and vertical regular blocks outlining the split-ribbed sections are very warm. Note that the horizontal foundation is warm except where it is poured out around the cellar door (large black arrow, Fig. 9). The square split-ribbed panels to the right of the door have nonuniform patterns which are darker and colder near the bottoms of the panels, tapering off near the tops (arrows, Fig. 10). This suggests settling, missing or wet insulation near the top portions of the panels. Many areas on the three faces of the new section exhibited this effect.

Figure 11 is a closeup thermogram of some of the conventional concrete blocks separating the split-ribbed sections horizontally along the first floor level of the east face. The outlines of some of the individual blocks can be seen as well as a mottled pattern that suggests moisture. This mottled pattern is hard to reproduce on the photographs but is quite clear on the CRT screen. The square white object in the center of the thermogram is the butt end of a floor beam on the z-axis; that is, it lies perpendicularly to the plane of the thermogram and disappears into the picture. Another warm beam end appears less clearly in the middle of Figure 12.

Figure 12 is a closeup of another group of east face split-ribbed panels showing the mottled pattern and the warmer areas near the tops of the panels. In addition, the bottom of the upper panel shows evenly spaced

Figure 9. South face of new section at Marshfield station.

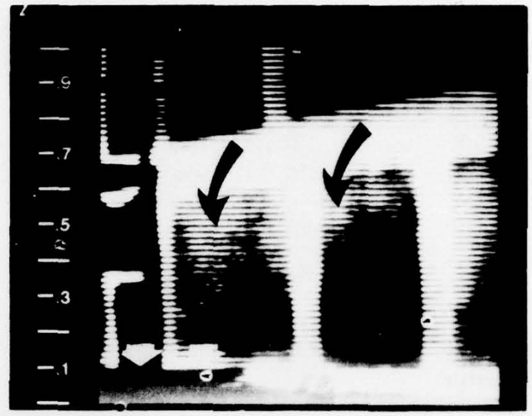

Figure 10. Nonuniform thermal patterns on south face.

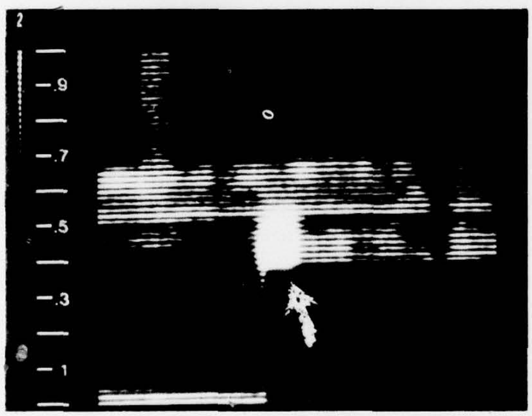

Figure 11. Closeup of floor beam on the east face.

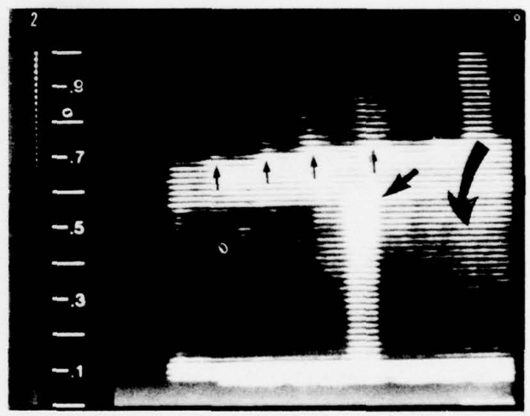

Figure 12. Outlines of 2×4 studding on the east face.

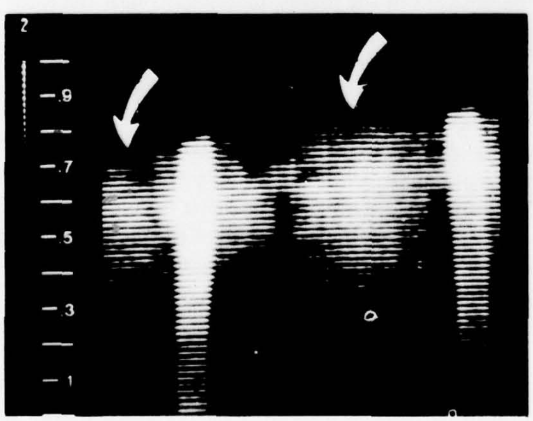

Figure 13. Nonuniform thermal patterns on the east face.

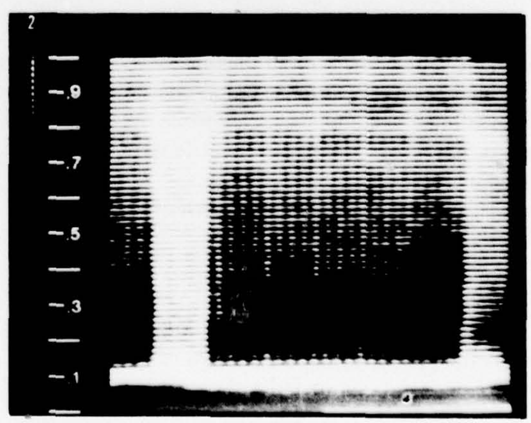

Figure 14. Nonuniform thermal patterns and block outlines on west face.

Figure 15. East face of new section.

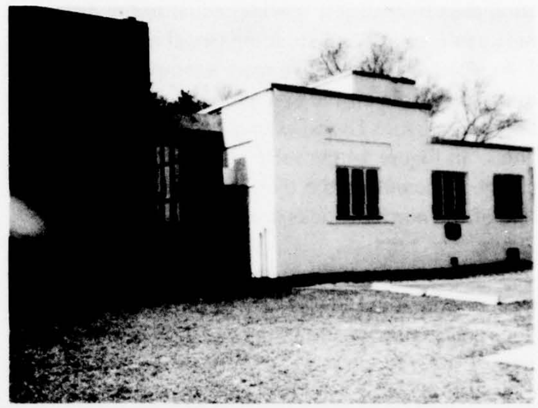

Figure 16. East face of new and old sections.

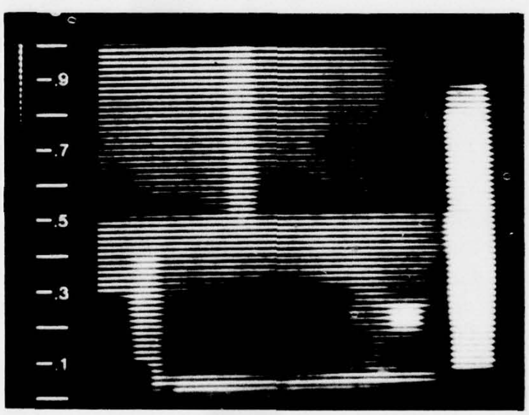

Figure 17. Comparison of cooler new section and warmer connecting section.

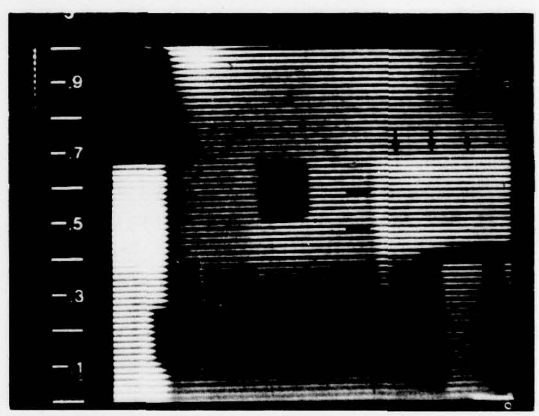

Figure 18. Covered vent and partially blocked window opening on east face.

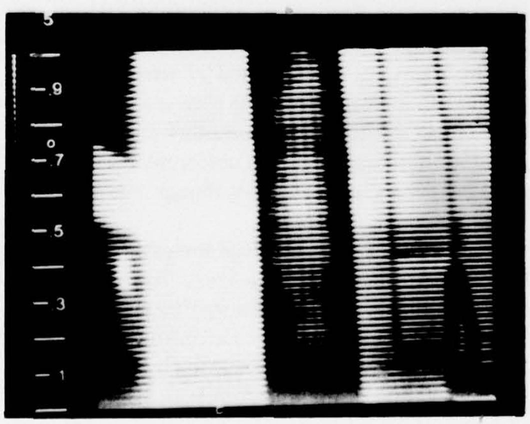

Figure 19. Glass connecting section and exterior chimney.

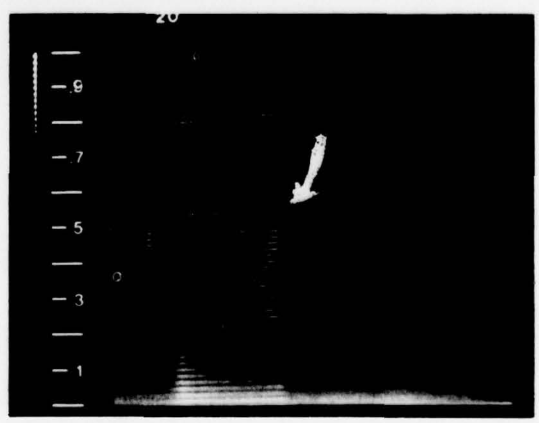

Figure 20. Glass panel under stairwell in connecting section.

anomalies that suggest spacings equal to the distance between internal 2x4 studding (small arrows, Fig. 12). Figures 13 and 14 are two more examples of the mottled pattern on the east and west faces of the new building. Figure 13 shows two large, circular, warm areas. In Figure 14 the vertical split-ribbed patterns can be made out on the thermogram as well as the outline of the normal blocks in the horizontal section above.

Figure 15 is a photograph of the east face of the new section with the east face of the glass connecting unit, and Figure 16 shows the east face of the old section. Figure 17, a thermogram of the east face of the new section, exhibits the familiar horizontal and vertical warm pattern separating split-ribbed panels. In addition, a small vent is visible in the lower right-hand corner. The glass interconnecting section at the right of the thermogram is much warmer than the new section face. The connecting section, at the left in Figure 18, is also much warmer than the old section. A cold and evidently well-insulated covered vent appears distinctly in Figure 18 but is hardly visible in the photograph. The blocked-in area where the old window opening was decreased in size to accommodate a smaller new window unit appears warmer than the face of the building itself (small arrows, Fig. 18). Figure 19 is a closeup of the east face of the glass connecting section. The hot vertical chimney appears cooler than the glass which surrounds it. These external chimneys waste a great deal more heat than chimneys constructed in the middle of a building. In this case the glass loses even more heat than the chimney, suggesting that this type of glass construction is not very energy efficient in cold weather.

Figure 20 shows a glass panel to the left of the chimney and connecting with the new section (white arrow). It was very hot (scale 20) yet serves no useful purpose because it is under the stairwell and unable to provide stairwell lighting. It should be replaced with an insulated panel.

Hull: Figures 21-33

The Point Allerton Station (Fig. 21) in Hull, Massachusetts, consists of a 30x13-m two-deck concrete masonry unit (CMU) barracks built in 1969, and a wooden two-deck duplex. The concrete blocks are stacked one on top of another (not staggered as in normal construction) so that insulation can be inserted in the block cavities. The roof consists of precast concrete panels and the foundation wall on the south face extends below grade into a heated basement, although the other faces are essentially a slab. Figure 22 is a photograph of the south face of the Point Allerton Station; Figure 23 is a thermogram of

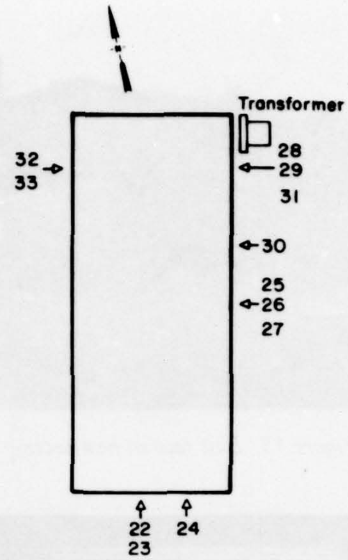

Figure 21. Point Allerton Station, Hull, Massachusetts.

the south face, which reveals an excessive amount of heat loss through the glass transom and around the door. The door itself appears insulated. The concrete block walls appear uniformly insulated and in Figure 24 the actual outlines around each block can be recognized. The foundation is excessively warm, as are the concrete blocks immediately above the transom level and the horizontal precast beams above them.

Figure 25 is a photograph of the main entrance on the east face of the building. It contains an excessively large glass area. There is no vestibule and the upper and lower open stairwells are just inside the door. Thermograms in Figures 26 and 27 were taken at a scale of 20, indicating that the glass is a very bad insulator compared with materials in other main entrances. The door itself appears to be uniformly dark and no leakage appears around it even though this door is heavily used.

Figure 28 is a photograph of the east face of the building near the northeast corner. The object in the lower right-hand corner is the transformer, and the boiler room window is immediately to the left. Figure 29 is a thermogram of this area which shows the hot, left rear section of the transformer housing at midnight (arrows). All lights were out and personnel asleep at this hour, and so the station's electrical load was minimal. Several of the other stations also showed hot transformers (see for example, Fig. 46 and 59). Figure 29 also shows that the boiler room window is much warmer than the other windows. Since this room is

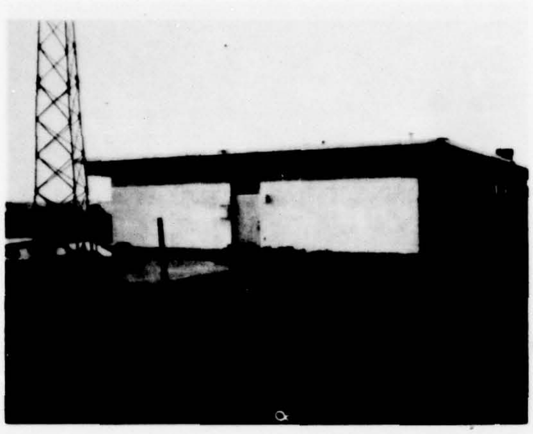

Figure 22. South face of the point Allerton station.

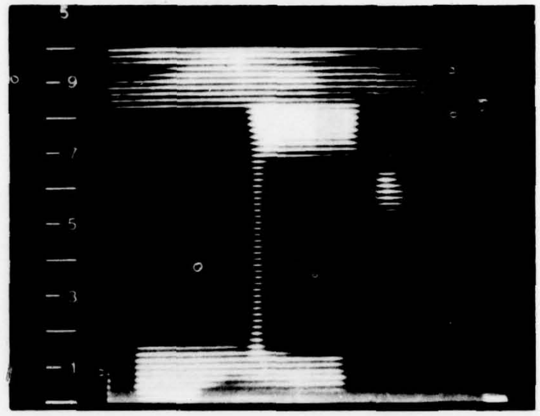

Figure 23. Closeup of warm foundation, glass transom and door exfiltration.

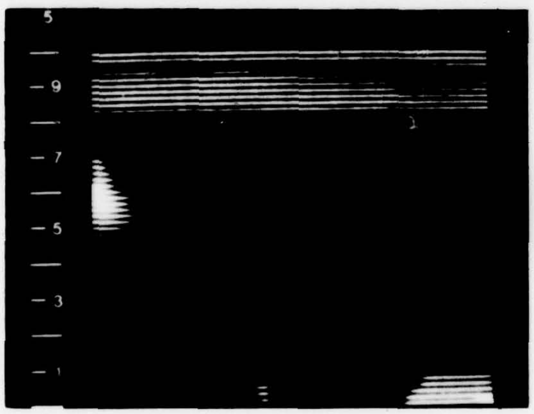

Figure 24. Cool wall of south face.

Figure 25. Main entrance on east face of Point Allerton station.

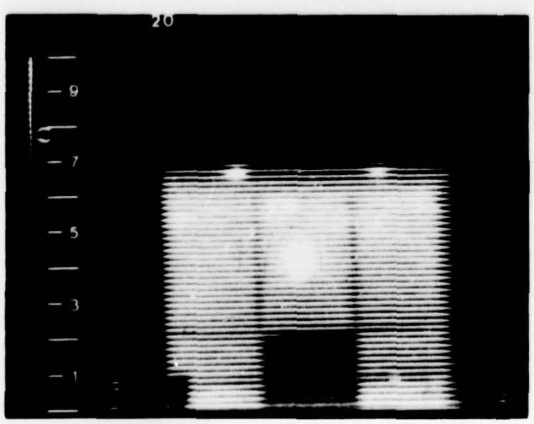

Figure 26. Glass surrounding main entrance door.

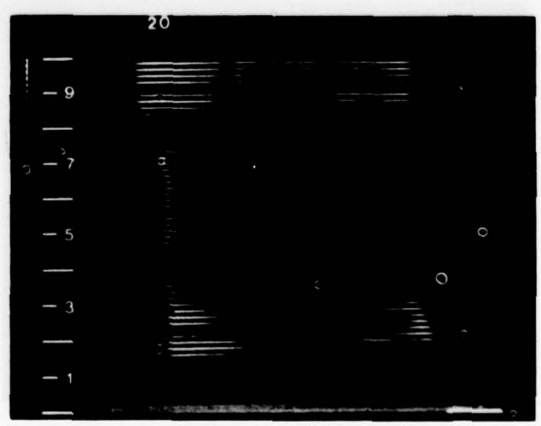

Figure 27. Main entrance door.

Figure 28. Northeast corner of east face of Point Allerton station.

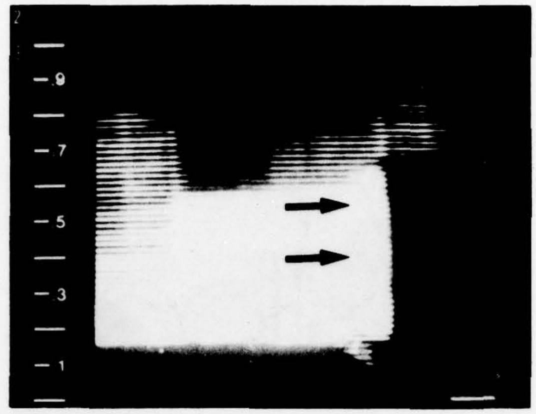

Figure 29. Boiler room window and transformer in northeast corner.

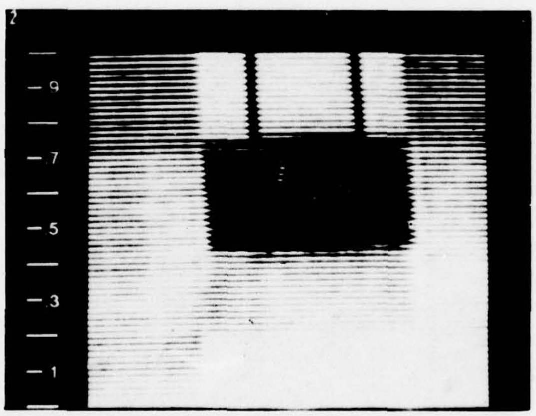

Figure 30. Thermal patterns in wooden panels separating first and second deck windows.

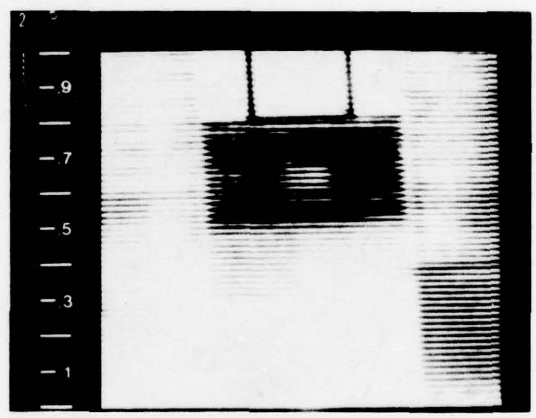

Figure 31. Radiator and 2×4 outlines under second deck window.

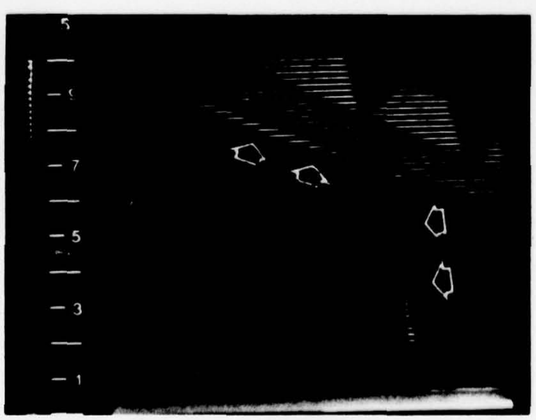

Figure 32. Exfiltration at window/wall interface.

Figure 33. Exfiltration between wooden panels and at panel/wall interface.

unoccupied, the window could be replaced with an insulated porcelain panel or other type of insulating unit.

Figures 30 through 33 show thermograms of typical first- and second-deck window units separated by what appear to be underinsulated wooden panels. Figures 30 and 31 show that the upper panels in both cases are cooler than the lower panels, and that an indistinct pattern appears in the center of each upper panel – apparently the outline of the room heaters and vertical 2x4 studs.

Figure 32 shows upper and right-hand leakage between the window frame and concrete block wall interface (arrows). Figure 33 shows horizontal leakage between the upper and lower panels and between the panels and the concrete block wall (arrows). These wooden panels should be compared with the much superior insulated porcelain panels at the Portland Base (Fig. 93-97).

Figures 29 and 31, both thermograms of the same location on the building, illustrate the effects of adjusting the camera's sensitivity. In Figure 29 the sensitivity was decreased in order to get the best reproduction of the hot window and transformer at the expense of overdarkening the wooden window panels. In Figure 31 the sensitivity was increased to lighten the wooden window panels for the best reproduction at the expense of washing out the transformer and hot window. These thermograms show that the thermographer cannot "manufacture" or create heat loss anamolies. He can only adjust the *total* picture for the best possible reproduction by choosing the proper scale and control setting.

Newburyport: Figures 34-46

The Merrimack River Station (Fig. 34), in Newburyport, Massachusetts, consists of a 24x23-m concrete masonry barracks with brick exterior built in 1973 and a heated brick boathouse (not surveyed). Figure 35 is a photograph of the northwest corner of the two-deck barracks and the single-deck mess extension. The communications room windows are on the first deck on either side of the corner. Figure 36 is a thermogram of the second deck window over the communications window on the north face, the top of the communication window appearing in the lower right of the thermogram. The upper window appears to be badly sprung along the right vertical meeting rail, and in addition, the upper third of the glass shows excessive leakage. Thermograms 36-40 are all taken at scale 10 which tends to be poor for windows. Figure 37 shows a thermogram of the communications center windows. The window on the left or north face appears to be in worse condition than the west face window. This is

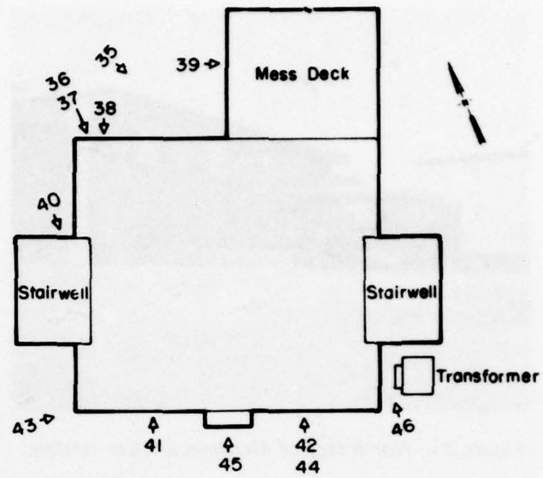

Figure 34. Merrimack River Station, Newburyport, Massachusetts.

confirmed by a closeup shot in Figure 38 of the north face window. Infiltration patterns on the glass can clearly be seen vertically along the left and right-hand glass/meeting rail interface. There is also leakage along the top horizontal window frame/brick interface.

Figure 39 is a thermogram of the west face of the mess deck. It shows excessive leakage through the single-pane glass door and glass transom above the door. All glass doors and transoms should be avoided in cold regions, from an energy conservation point of view, in favor of some type of insulated door. Although leakage is occurring in the upper right corner of the double-pane window unit to the left of the door, this window, and the one on the right in Figure 35, are still much cooler than the door glass. All three units are in the same large room.

Figure 40 is a thermogram of the north face of the stairwell which is just to the right and out of view in Figure 35. The narrow vertical pattern is the warm window glass extending from the foundation to the tower of the stairwell. The thermogram indicates that the stairwell is excessively warm, and since it is not heated, it must be robbing heat from the building (chimney effect). Perhaps these vertical windows should be replaced with insulated panels on the north face to conserve energy. The door is indicated on the thermogram immediately to the right of the glass pattern as the horizontal and vertical patterns below the circular pattern which is the light above the door. It indicates that the door leaks at its top interface but not as badly as many other stairwell doors at other stations.

Figures 41 and 42 are photos of the south face of the barracks. Figures 43-46 are thermograms of this

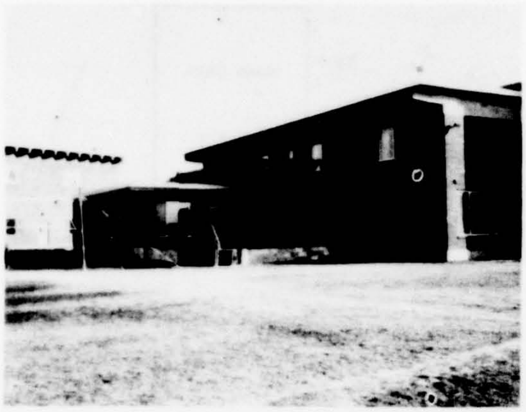

Figure 35. North face of Merrimack River station.

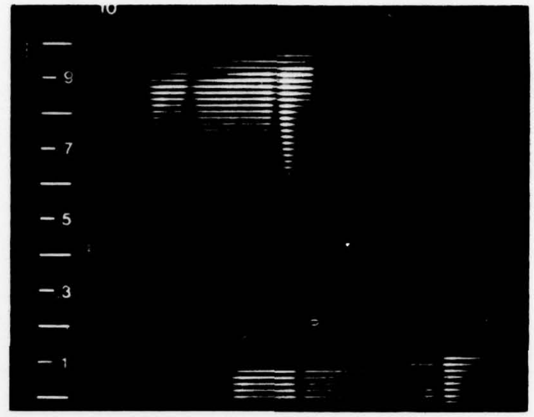

Figure 36. Second deck window.

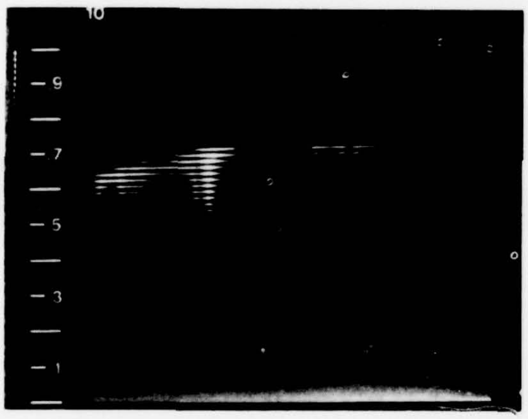

Figure 37. Two communications center windows.

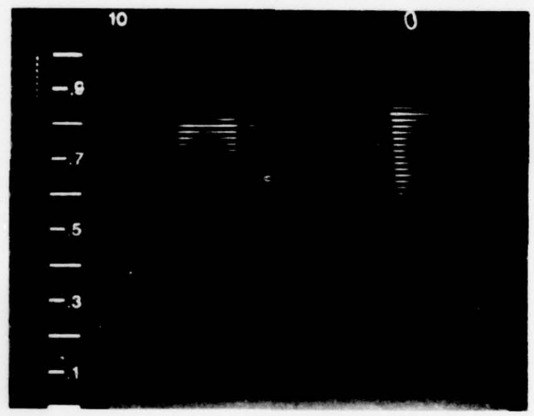

Figure 38. Closeup of communications center window on north face.

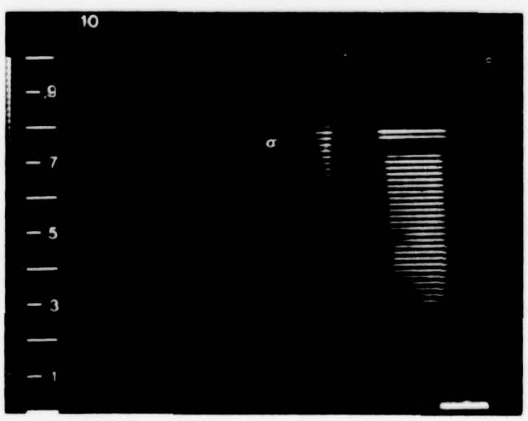

Figure 39. Glass door on west face of mess deck.

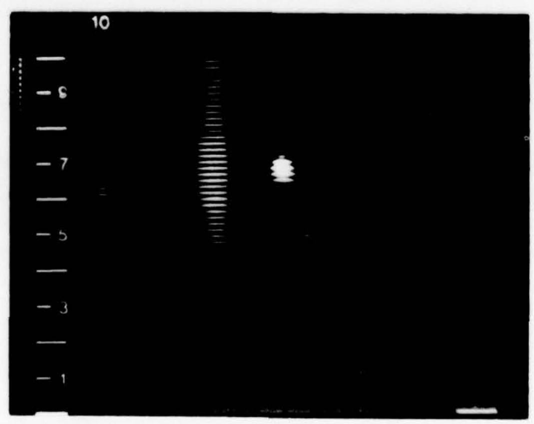

Figure 40. Warm vertical window on north face of unheated stairwell.

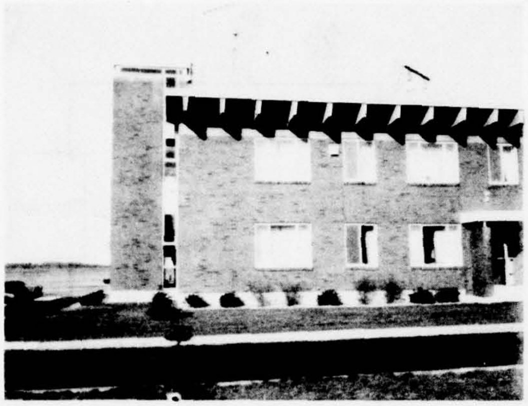

Figure 41. Southwest section of south face of Merrimack River station.

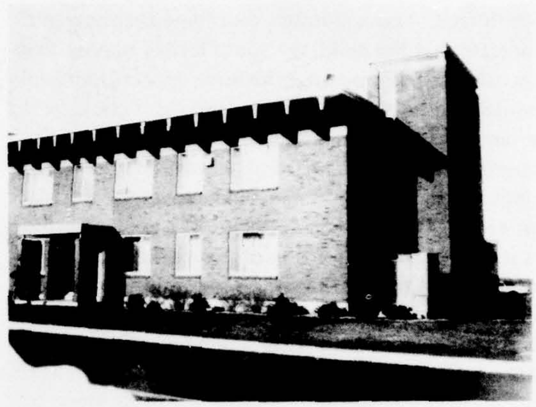

Figure 42. Southeast section of south face.

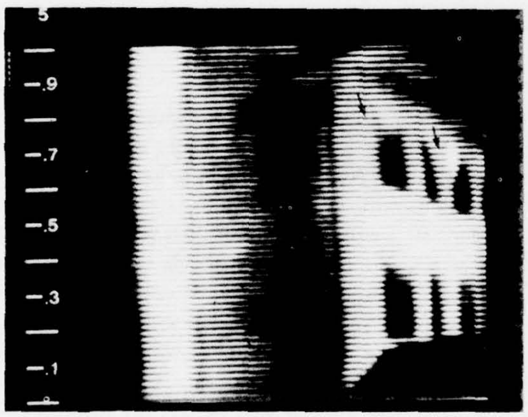

Figure 43. Solar effect on southwest corner.

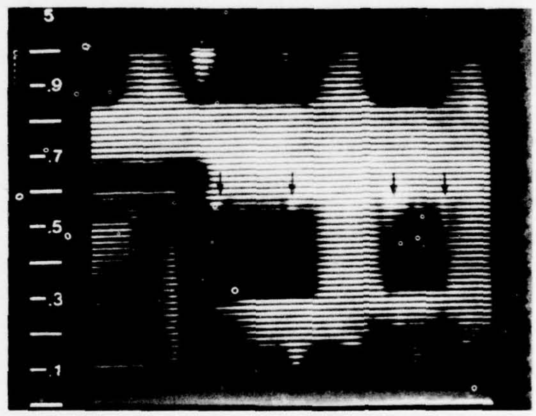

Figure 44. Main entrance with vestibule and boiler room on south face.

Figure 45. Second deck window exfiltration in spite of drawn drapes.

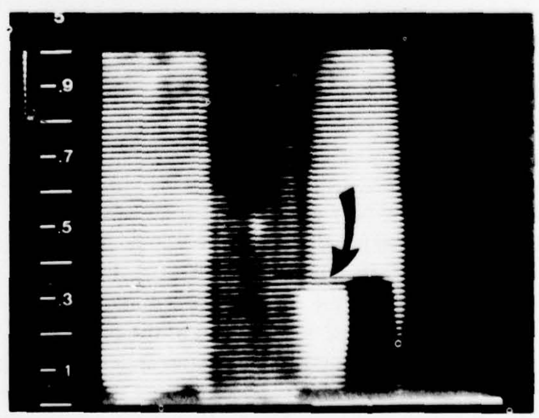

Figure 46. Hot transformer in southeast corner of station.

south face. You will notice that these thermograms indicate that the building's south face is warmer than the window glass because the brick appears uniformly white and the glass uniformly dark. This could be the effect of the sun, since thermograms were taken at approximately 1940 hours. The west face, however, does appear cool, and one would expect the west face to exhibit the same solar effects. The cooler west face is shown as the left portion of Figure 43. At first it was thought that thermograms taken during this solar effect would have little or no value, but Figures 43 and 44 indicate that leakage around window openings appears much more prominently at greater distances due to the large contrast between the black glass and the white heat loss. This can readily be seen in the upper portions of the first and third windows of the second deck in Figure 43 (small black arrows) and the first deck windows to the right of the entrance in Figure 44 (small black arrows). This leakage occurs even though all the drapes were drawn on the south face and all windows were checked by the duty officer to ensure that they were closed. The window immediately to the right of the entrance in Figure 44 is in the boiler room, which is quite tight as compared to boiler room windows at other stations. The main entrance in Figure 44 is also good, as compared to some main entrances with vestibules at other stations. The left pane of the upper left window in Figure 45 (black arrow) has excessive leakage even though the drapes were drawn and the window closed.

Figure 46 shows an excessively hot transformer in the southeast corner (black arrow); however, the thermogram was taken at 1955 hours when most of the personnel were still awake and using the building's facilities. The southeast vertical stairwell windows in Figure 46 appear cooler than the northwest ones in Figure 40. The south face of the stairwell in Figure 46 appears as warm as the south face of the main portion of the building, but the east face appears cooler.

Gloucester: Figures 47-59

Gloucester Station (Fig. 47), in Gloucester, Massachusetts, consists of a 24x23-m concrete masonry barracks with brick exterior built in 1974, and a heated brick boathouse (not surveyed). Figure 48 is a photograph of the southeast corner of the three-deck barracks and the mess deck at Gloucester Station. Figure 49 is a thermogram of the right-hand portion of the second and third decks, with the windows of the bathrooms near the center. The right-hand panes appear cooler than the left-hand ones, which appear warmer than the other glass panes on this face. The third-deck vent to the right of the window is closed, while the second-deck vent is open with its exhaust fan operating. The pattern made

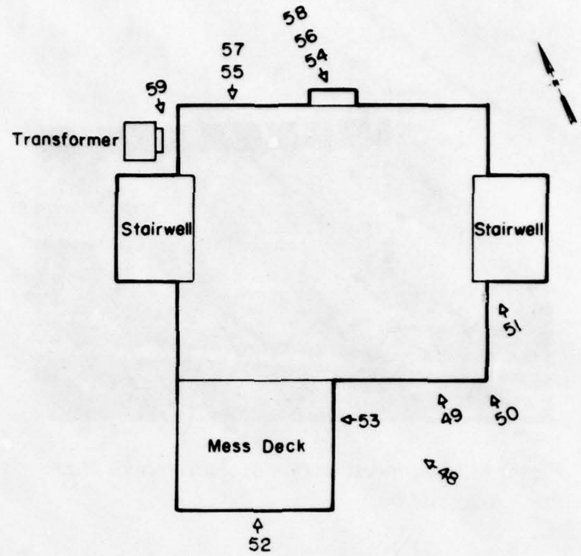

Figure 47. Gloucester Station, Gloucester, Massachusetts.

by this vent is not as intense as the plume from a vent on the north face (Fig. 55). Evidently the wind is drawing the warm air from the building's north face but inhibiting its outflow on the south face.

Figure 50 is a thermogram of the communications center windows located on either side of the southeast corner of the first deck. Both windows are openings for the same room, yet the window on the left (south face) is uniformly dark or cool while the window on the right (east face) appears to badly sprung. It has a serious infiltration pattern along the right vertical meeting rail as well as the upper portion of the left glass panel. The foundation also appears warmer than the wall at this station.

Figure 51 is the stairwell door to the right of the east face communications center window. It shows heat loss completely around the door as well as through the small glass panel in the door. The vertical stairwell windows are indistinctly warm but cooler than the door/wall interface. A warm vertical construction joint also appears immediately to the left of the stairwell windows. The horizontal second deck is indistinctly visible in both Figures 50 and 51.

Figure 52 is a thermogram of the galley door on the south face of the mess deck behind the jeep in Figure 48. Note that the light above the door is off and the light fixture cold. Leakage is evident around the door, especially along the top and right-hand interfaces. This thermogram was taken at 2249 hours, long after the galley equipment had ceased operation, although this door is used frequently by station personnel at night.

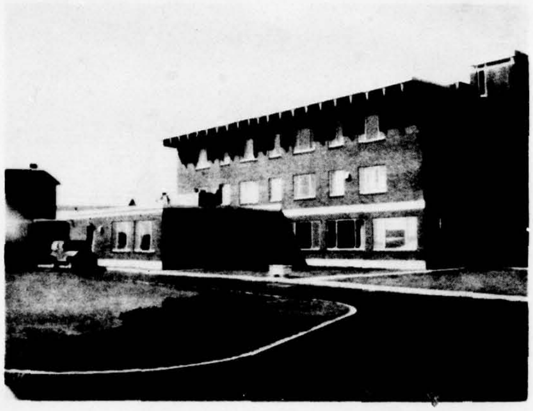

Figure 48. Southeast corner of Gloucester station.

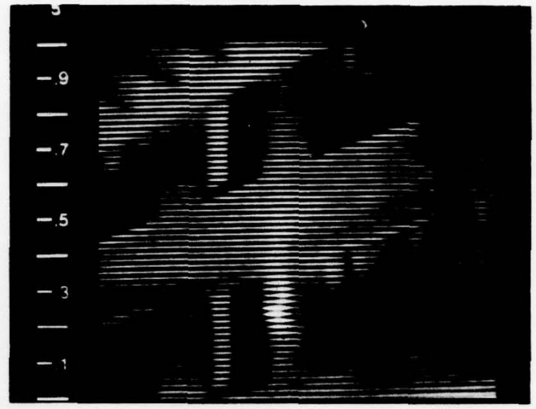

Figure 49. Windows on southeast face.

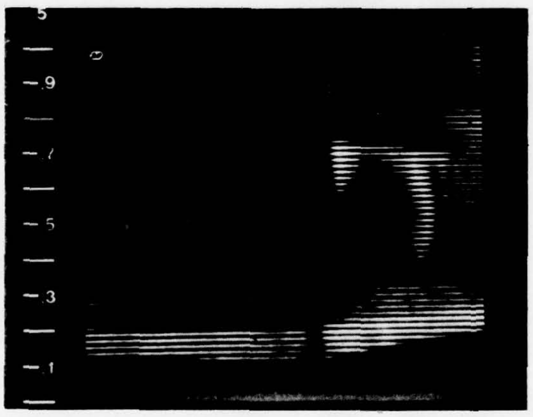

Figure 50. Communications center windows.

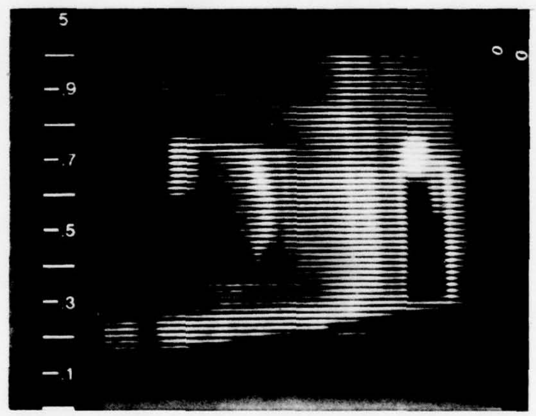

Figure 51. Stairwell door and vertical construction joint.

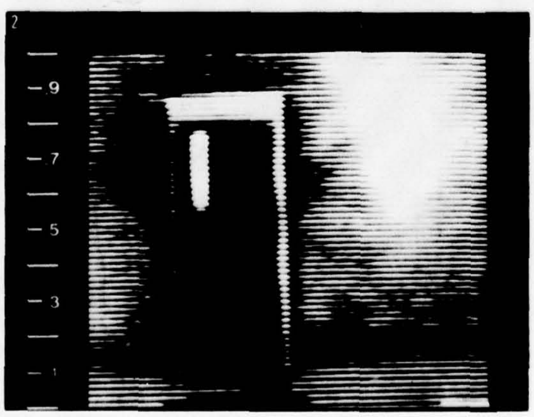

Figure 52. Galley door on south face of mess deck.

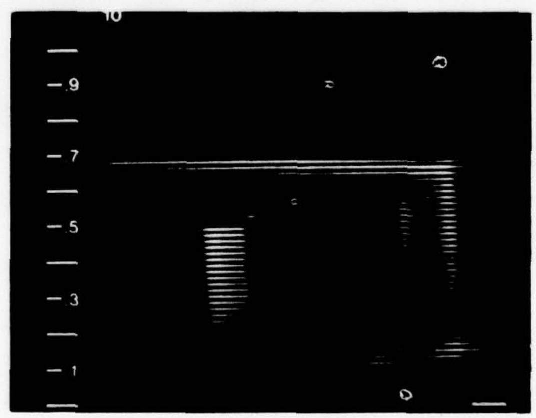

Figure 53. East face of mess deck.

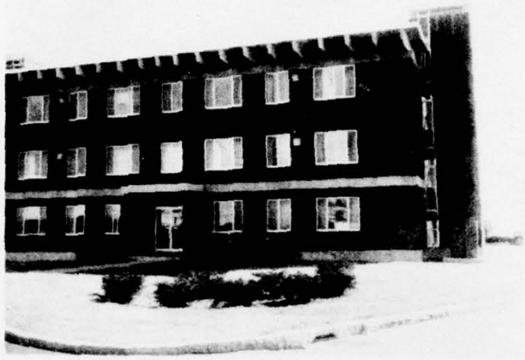

Figure 54. West section of north face of Gloucester station.

Figure 55. Plume of hot air coming from bathroom vent.

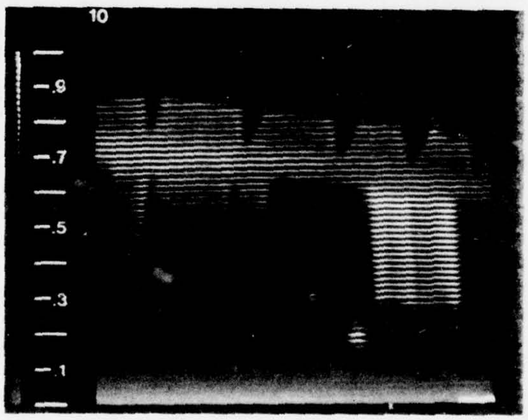

Figure 56. Excessive leakage from window in unoccupied boatswain's locker.

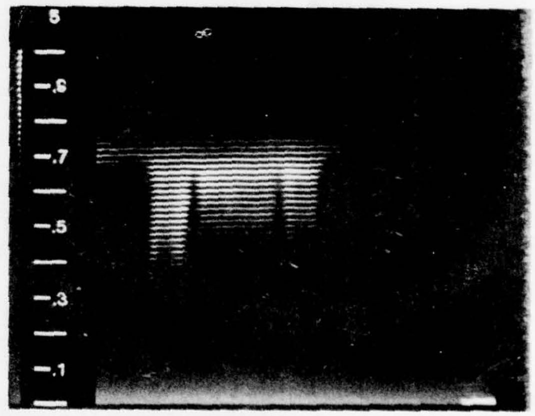

Figure 57. Excessive exfiltration from window/wall interface.

Figure 58. Boiler room window to right of main entrance door.

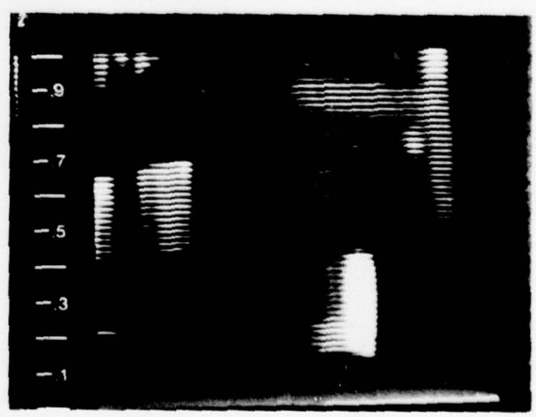

Figure 59. Hot transformer at 2316 hours.

Figure 53 is a thermogram of the glass door in the east face of the mess deck which is nominally at the same inside temperature as the galley. However, this thermogram, taken at scale 10, shows that the windows on either side of the door, which all open into the same room, are much more energy efficient. The light above this door is also turned off.

Figure 54 is a photograph of the north face, west section of the Gloucester Station. Figure 55 is a thermogram of a vent to the right of the second deck bathroom window. The plume of hot air from the vent is blowing down and to the right or west even though the wind was from the south-southwest at 18 knots.

Figure 56 is of a window on the third-deck floor over the main entrance that exhibits excessive heat loss at scale 10. Since the room is an unoccupied boatswain's locker, the window could be replaced with an insulated porcelain panel to conserve energy.

Figure 57 is of the third deck window on the upper right in Figure 54. The patterns on the glass suggest infiltration loss as well as the fact that the top horizontal interface is much warmer than most of the other windows on this face.

Figure 58 is of the glass main entrance door, which displays some heat loss at scale 5, despite a closed vestibule inside. Of more concern, however, is the exceedingly warm window immediately to the right of the main entrance. Windows of the unoccupied boiler room could be replaced with insulated panels to conserve energy. In Gloucester Station's case, the boiler was not providing sufficient heat for the building and so most of the personnel had electric heaters in their rooms. The tremendous electrical load at 2316 hours is illustrated in Figure 59 by the hot transformer in the lower right corner of the thermogram, wh` corresponds to the lower right of the Figure 54 photograph. The vertical stairwell windows and the horizontal second floor can also be seen behind the transformer.

Boston: Figures 60-72

Boston Support Center (Fig. 60) in Boston, Massachusetts, consists of several brick buildings built in the 1890's and early 1900's: building 1 (43 x 23-m 5-deck), building 2 (34 x 27-m, 5-deck), building 3 (34 x 26-m, 5-deck), building 4 (79 x 24-m, 5-deck), building 8 (60 x 42-m, 7-deck) and several smaller structures. Figure 61 is a photograph of the northeast corner of building 8, which was recently renovated. Figure 62, a thermogram of building 8, shows that the left or east face is warmer than the right or north face. This may indicate that the hallways which are parallel to this east face are warmer than the offices along the north face. Also several outlines just to the right of the corner suggest former windows that have been covered over. Figure 63 shows that building 4 (to the left) is much warmer than building 8. Building 4 and the other older unrenovated buildings are all much warmer than building 8, and this is only one of several clues to the fact that station personnel are having trouble maintaining and regulating the temperatures in the older buildings.

Figure 64 is a photograph of the north face of building 4, and Figures 65 and 66 are thermograms of the

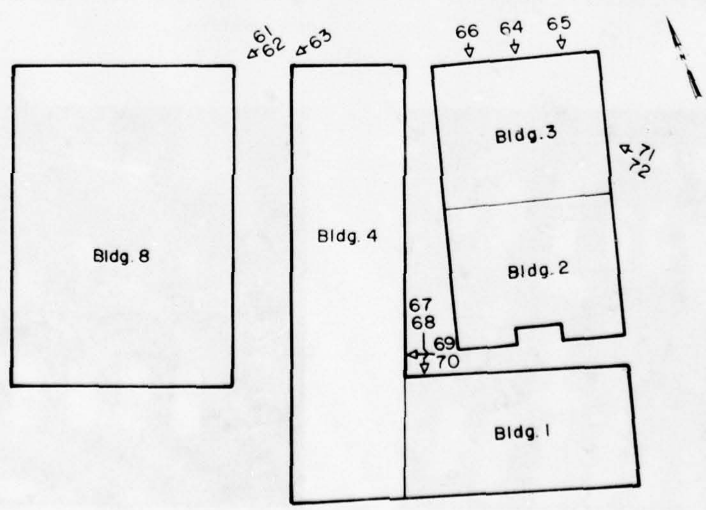

Figure 60. Boston Support Center, Boston, Massachusetts.

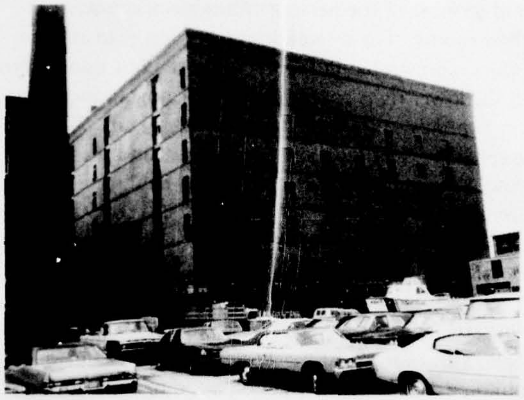

Figure 61. Northeast corner of recently renovated building 8.

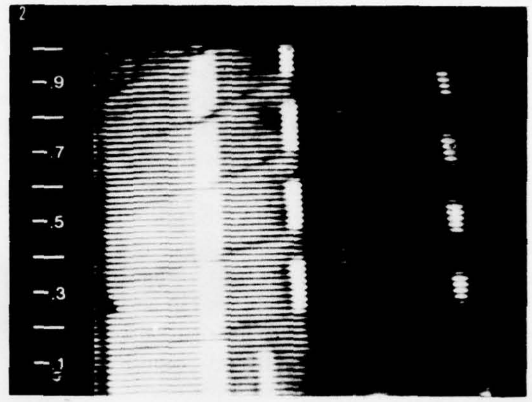

Figure 62. East face of building 8 on left and north face on right.

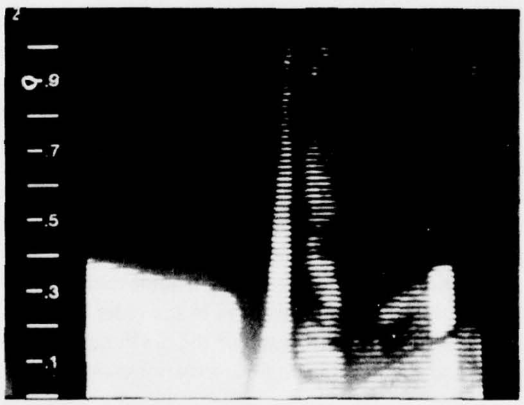

Figure 63. Building 4 on left appears warmer than building 8 on right.

Figure 64. North face of building 4. Arrow points to new windows.

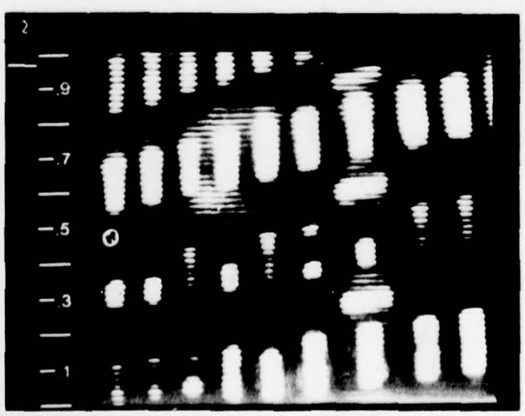

Figure 65. Thermal outlines of new windows and original windows.

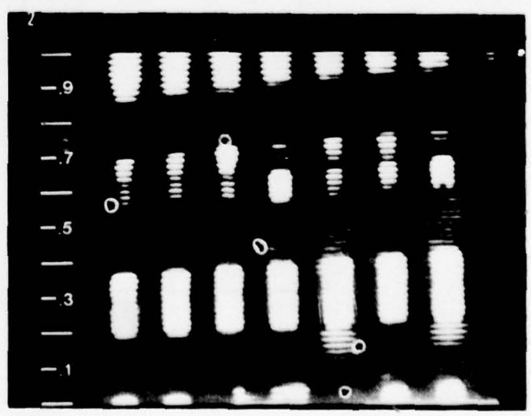

Figure 66. Thermal patterns of some of the new windows.

Figure 67. Arrows indicate air conditioner units on north face of building 1.

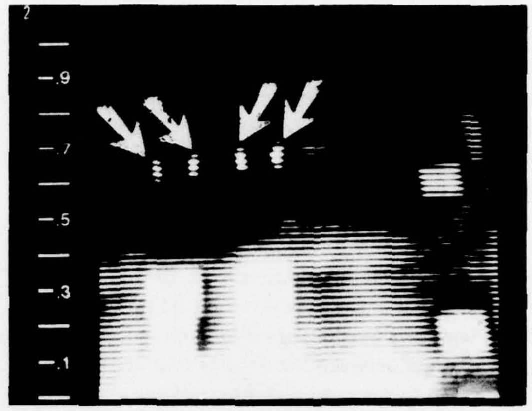

Figure 68. Leaks on both sides of the air conditioner units.

Figure 69. Bricked-in windows on east face of building 4.

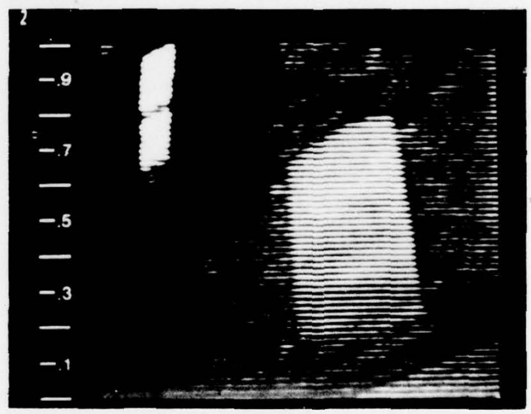

Figure 70. Bricked-in window and surrounding brick wall.

Figure 71. Upper decks on east face of building 3.

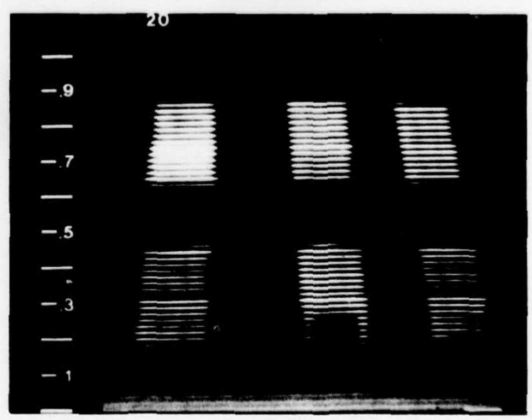

Figure 72. Extremely warm top deck windows on east face of building 3.

north face. In addition to the somewhat obvious heat loss patterns due to open windows and/or storm windows, Figures 65 and 66 show the comparison between some new windows on the third deck and the original windows. In Figure 65 the second horizontal row from the bottom consists of new windows, and the warm rectangular area of each window is of smaller area than that of the old windows, although all windows are the same size. Also several of the windows have dark cool patterns which indicate how well the storm windows would work if kept closed. The warm granite stones between the vertical stairwell windows can be seen to the right of center in Figure 65. The third horizontal row in Figure 66 is of the third-deck windows to the right of the stairwell. In Figure 65, the fourth-deck windows to the left of the stairwell exhibit a large circular warm pattern on the brick. This type of typical pattern showed up on many of the faces of all the older buildings and indicates heat loss problems in the brick walls themselves.

Figure 67 is a photograph of the north face of building 1 taken from the passageway between buildings 2 and 4. Note the two air conditioner units in the windows on the top deck. Figure 68 is a thermogram of these two windows. It shows how the windows themselves and the air conditioner units are dark or cool but the area to the left and right of each air conditioner leaks badly. The brick wall exhibits a cool pattern along the top deck but a warm pattern along the deck below it.

Figure 69 is a photograph of the east wall of building 4 taken from the passageway between building 1 and building 2. The corresponding thermogram, Figure 70, shows how one of the bricked-over windows is much warmer than the surrounding brick wall. These thermograms illustrate the value of IRTB in determining just how successful the filling-in of a window opening really is when using brick and/or concrete block without insulation.

Figure 71 is a photograph of the north section of the east face of building 3. The new windows on the third deck (black arrow) exhibited the same improved thermal patterns as those on the north face in Figures 65 and 66. Figure 72 is a thermogram of some fourth and fifth deck windows. This and other thermograms of the rest of the fourth and fifth decks show that these top two decks were very much warmer (scale 20) than the lower ones. It has been our experience that buildings exhibiting extremely warm top decks and much cooler lower ones, together with numerous open windows in the winter, have a very serious temperature regulation problem. Invariably we find that only one single zone thermostat controls the whole building. Corrections to the heating system, such as using multiple zones, must be undertaken in addition to installing energy efficient windows and properly insulated walls.

New Castle: Figures 73-85

The Portsmouth Harbor Station (Fig. 73) in New Castle, New Hampshire, consists of a 35x12-m concrete masonry barracks with brick exterior built in 1967, a 18x9-m reserve building with brick exterior, and a motor pool with concrete block exterior. Figure 74 is a photograph of the east section of the north face of the two deck barracks and Figure 75 is the west section of the north face. Figure 76, a thermogram of the east section of the north face, shows a badly sprung stairwell door, a garage door with excessive leakage

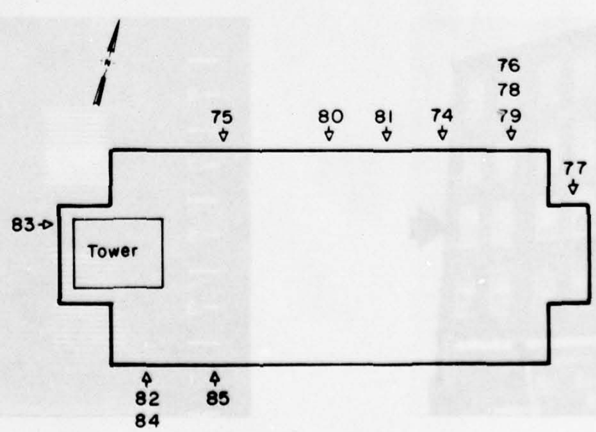

Figure 73. Portsmouth Harbor Station, New Castle, New Hampshire.

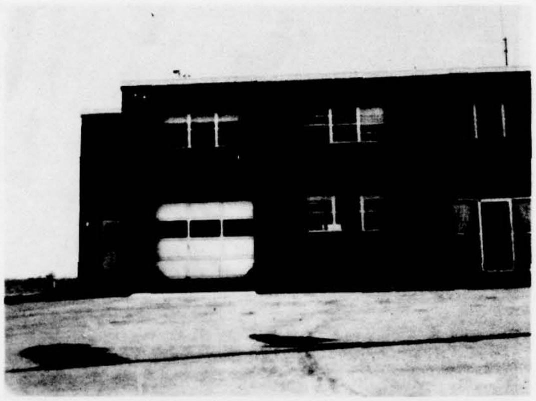

Figure 74. East section of north face of Portsmouth Harbor station.

Figure 75. West section of north face of Portsmouth Harbor station.

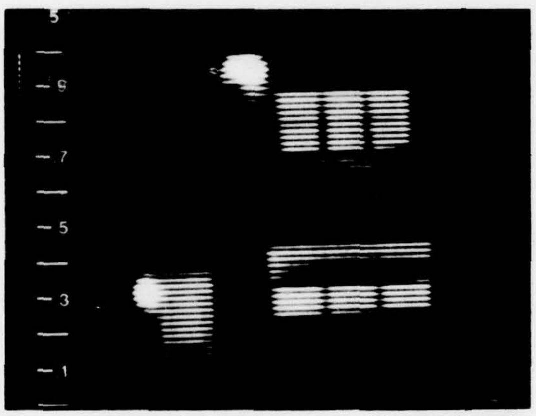

Figure 76. Stairwell door badly sprung, garage door and second deck window.

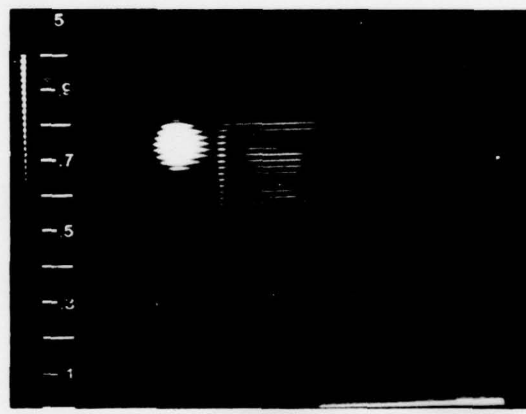

Figure 77. Badly sprung stairwell door on northeast corner of building.

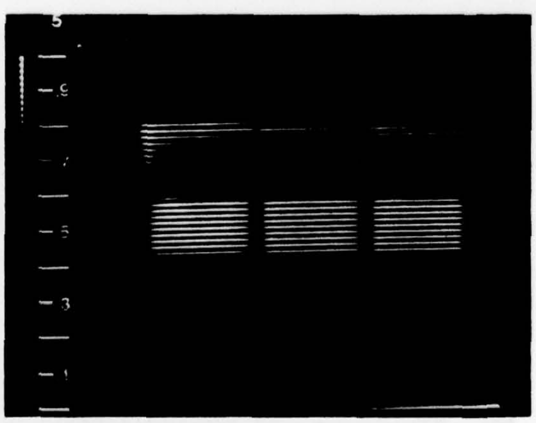

Figure 78. Garage door in northeast corner of building.

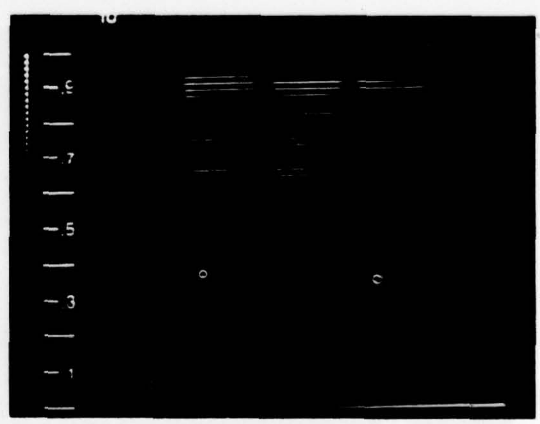

Figure 79. Windows on the north face with drawn drapes.

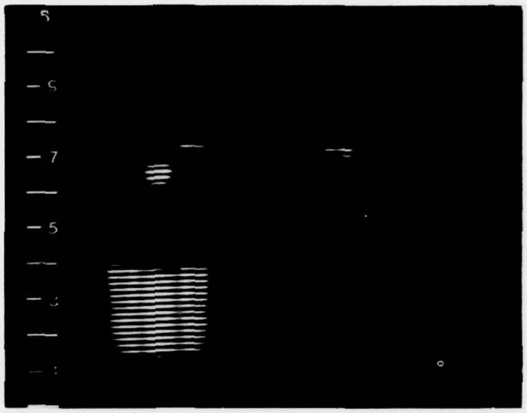

Figure 80. Comparison: entrance on right with vestibule, and entrance on left without vestibule.

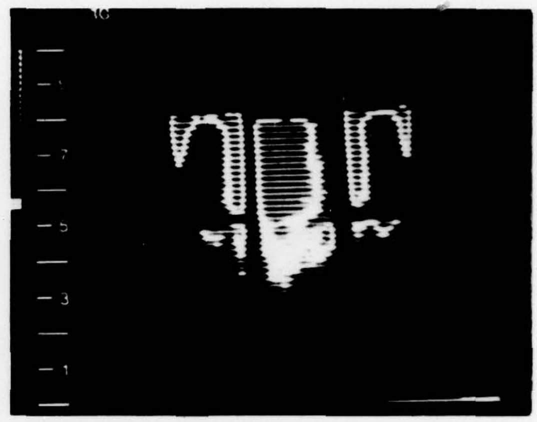

Figure 81. Isothermal infiltration patterns on glass entrance.

Figure 82. Southwest section of south face of Portsmouth Harbor station.

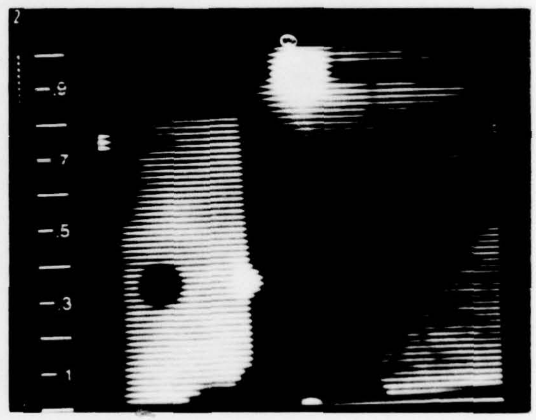

Figure 83. Mottled moisture pattern on west face of stairwell.

Figure 84. Open second deck windows on south face.

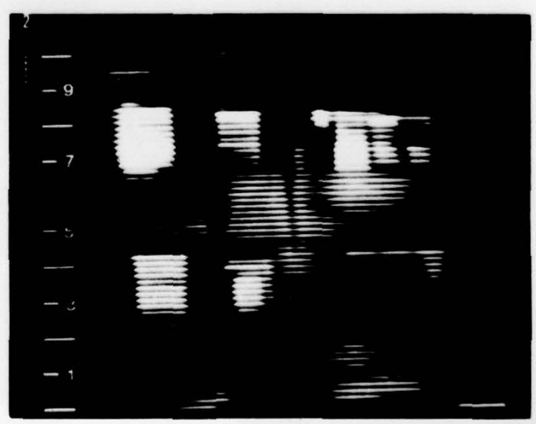

Figure 85. Radiator leakage under windows on south face.

through the glass windows and the top horizontal interface, a second-deck window exhibiting excessive leakage, in spite of the fact that the drapes are drawn, and the vague outline of a radiator under the window.

Figures 77-79 are closeups of the stairwell door, garage door, and window, respectively. Figure 77 is a confirmed example of what a badly sprung metal door, i.e. a door bent by the strong winds, looks like in a thermogram. The upper horizontal and vertical interfaces show a wide thermal heat loss pattern whereas there is little leakage along the bottom interface. This could result from the bottom interface experiencing infiltration of cold air while the top interface is allowing exfiltration of warm air. Other stations subjected to the same high winds (Boothbay Harbor and Jonesport) had doors with similar patterns.

Figure 78 is a closeup of the wooden garage door showing the excessive top horizontal leakage and the warm window glass. However, this garage door was not as bad as those at some of the other stations. Figure 79 is the window over the garage door taken at scale 10. All the windows on the north face were closed and had drawn drapes but still exhibited some leakage. This station often has the problem of the entire north face being very cold and the entire south face very warm.

In Figure 80 (a thermogram of the west section of the north face) other window heat loss problems can be noticed and the faint outlines of heaters under the windows are evident. In addition, the two all-glass doors are compared thermographically. The one on the left, for the Teletype Repair Office, is warmer than the main entrance on the right which has an enclosed vestibule. Figure 81 in a closeup thermogram of the glass teletype repair door which uses the camera's isotherm function. The irregularly shaped sinusoidal isothermal patterns on the glass are typical of isothermal patterns observed on windows and doors that have heat loss problems. It is suspected that these patterns are related to the amount of infiltration, where it is taking place, and whether it is infiltration or exfiltration. Further research needs to be done in order to learn the cause of these interesting patterns.

Figure 82 is a photograph of the west section of the south face of the barracks and Figure 83 is a thermogram of the west face (extreme left in Fig. 82), the right-hand section being the stairwell under the tower. The west face of the barracks stairwell exhibited a mottled pattern but the west face of the left-hand portion (where the mess area is located) did not. The round spot on the wall is a sign. For some reason, this station had a mottled pattern only on a portion of the west face which is minimal in size compared to moisture patterns at some of the other stations.

Figures 84 and 85 are thermograms of the south face that illustrate one of the major problems at this station. The south face is so warm that most of the windows are kept open all night long. In fact, the dark object in the lower left-hand corner of the left second-deck window is a drape blowing in the breeze. This is the office that has the only thermostat controlling the entire building, and the window is deliberately kept open by the personnel occupying the north face rooms in order to call for enough heat. As a result the personnel occupying the south face rooms keep their windows open because they are too warm. The radiators under the windows are clearly seen in thermograms 84 and 85. The three windows in lower left of Figure 84 are the galley windows which do not have radiators under them.

The photograph and thermogram on the cover show the lighthouse at the New Castle Coast Guard Station. Heat loss is evident in the upper portion of the lighthouse wall and glass.

South Portland: Figures 86-98

The Portland Base (Fig. 86) in South Portland, Maine, consists of a 71- x 13-m concrete masonry barracks with brick exterior built in 1967, an 24 x 13-m

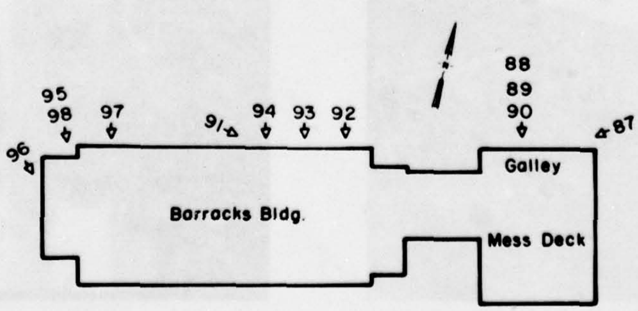

Figure 86. Portland Base, South Portland, Maine.

Figure 87. Northeast corner of mess deck of building 6 at Portland Base.

Figure 88. Window on north face with insulated porcelain panels.

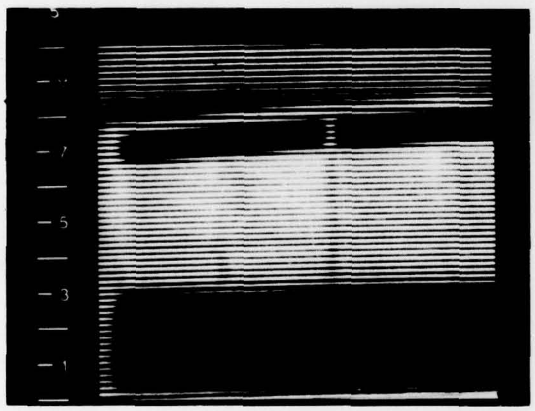

Figure 89. Panels above and below the glass appear cool.

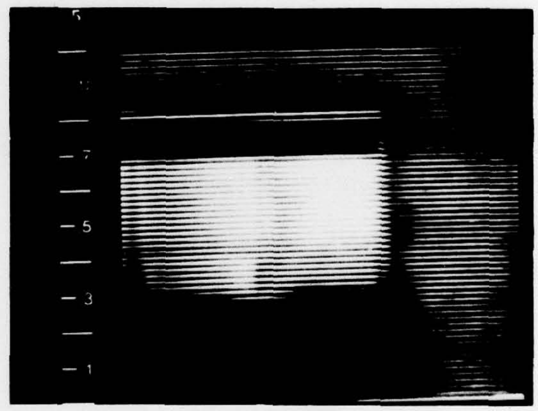

Figure 90. Interfaces around panels.

Figure 91. North face of two deck barracks section of building 6.

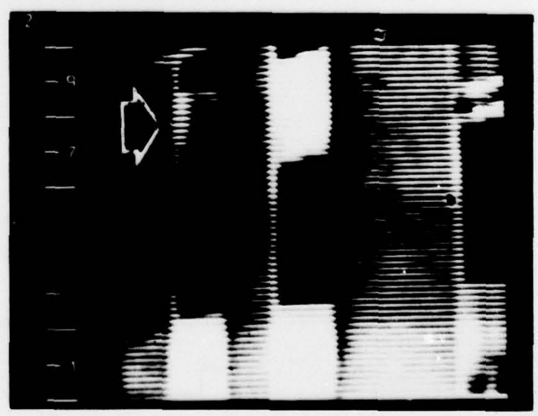

Figure 92. Thermal pattern on second deck window (arrow).

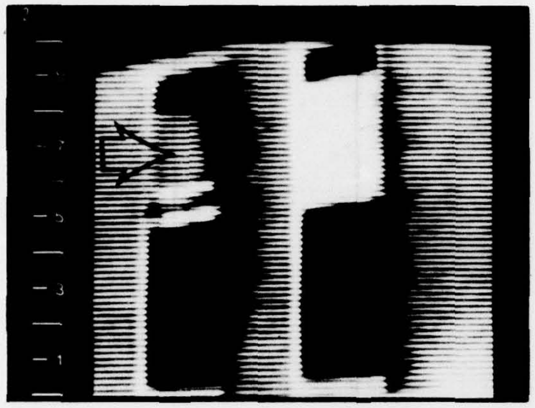

Figure 93. Second deck window opened, lower section.

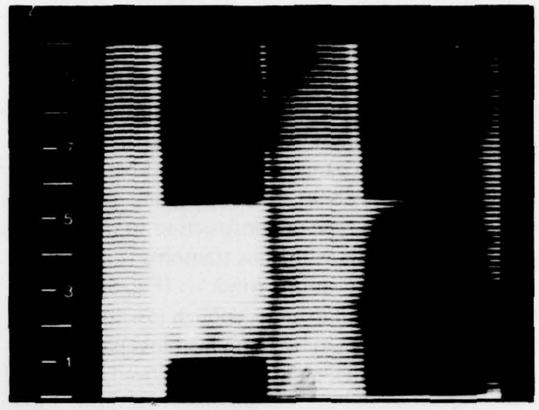

Figure 94. Cool porcelain panels, note cool window on right.

Figure 95. Northwest corner of two-deck barracks section of building 6.

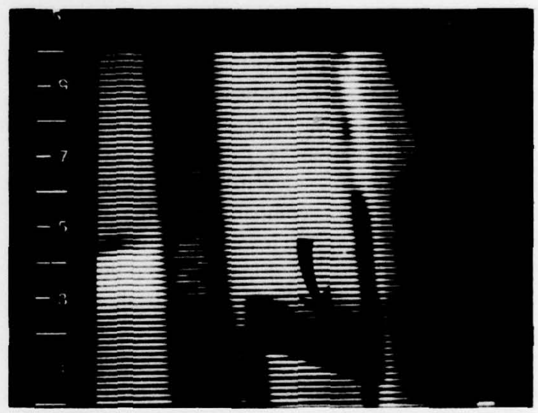

Figure 96. Porcelain panel between first and second deck windows.

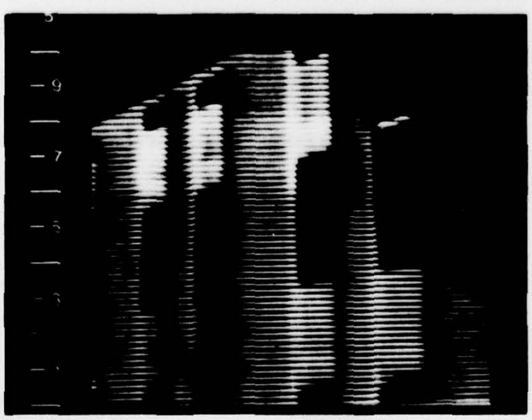

Figure 97. Cool porcelain panels, note cool window on upper right.

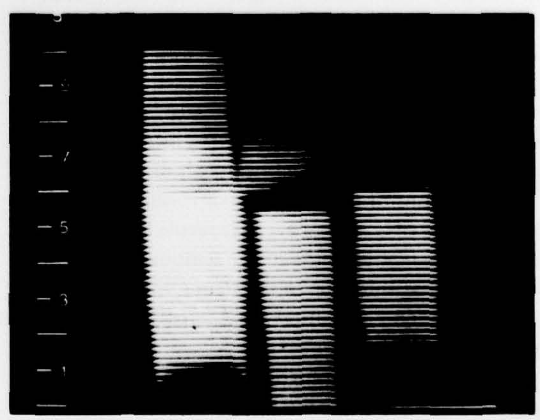

Figure 98. Door in northwest corner with leakage through the surrounding glass.

administration building with brick exterior, a 30x12-m industrial shop building with concrete block exterior and a 26x9-m navigation shop building with concrete block exterior. Figure 87 is a photograph of the northeast corner of the mess deck of building 6. White insulated porcelain panels are above and below the five windows. Figures 88-90 are thermograms showing the superiority of this type of construction to other types, such as the windows with glass transoms (Fig. 134) or the numerous badly sprung windows (Fig. 50). Although this glass still exhibits enough loss to warrant the use of scale 5, there were no heat loss patterns between the wall/panel, panel/glass, glass/wall, and glass/frame interfaces despite the northern exposure. Figure 88 shows the right-hand single window, Figure 89 the left two of the three middle windows, and Figure 90 the right hand middle window.

Figure 91 is a photograph of the north face of the two-deck barracks section of building 6 with the mess deck in the background. Note the white insulated porcelain panels between the first- and second-deck windows, above the second-deck windows, and below the first-deck windows. Figures 92-94 are thermograms of these window sections that show the superiority of these panels (black rectangular patterns between upper and lower windows) as compared with the wooden panels between upper and lower windows in the Hull Station (Fig. 30 and 31). Figures 95 and 96 show a wooden frame stored against the west wall, which points towards the interface between the porcelain panel and the first deck window. The porcelain panel is just as dark (cold) as the wooden frame at ambient temperature (7.2°C).

Four types of window patterns are evident in Figures 92-94 and 97. Most of the windows are uniformly white but two are almost black, as seen in the right-hand window in Figure 94 and the right-hand upper window in Figure 97. The left-hand upper window in Figure 92 (arrow) shows a dark vertical pattern in the middle with a white pattern at the vertical edges, while the upper left window in Figure 93 (arrow) shows the reverse. What these patterns mean is not clear; it could be the effect of drawn drapes, opened lower portions of the windows, or room heaters that were turned off. In any event it seems clear from the even rectangular patterns of the windows and panels at scale 2 that this type of construction is vastly superior for energy conservation in cold regions to that of other stations.

Figure 98 is a thermogram of the stairway door in the northwest corner, and except for the unnecessary loss due to the large glass area, the door is thermally tight. This is probably because this door is out of the general path to the other buildings on the base and is rarely used. It exhibits the same good fit as the galley door at Boothbay Harbor.

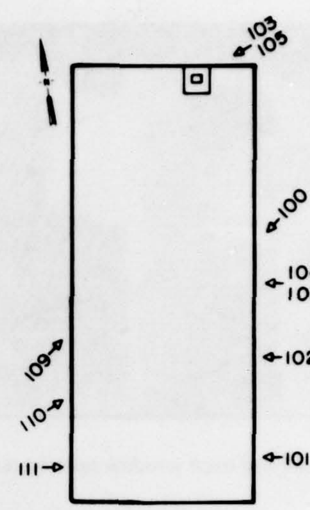

Figure 99. Boothbay Harbor Station, Boothbay Harbor, Maine.

Boothbay Harbor: Figures 99-111

The Boothbay Harbor Station (Fig. 99) in Boothbay Harbor, Maine, consists of a 29x12-m concrete masonry barracks built in 1967, and a wooden 13x9-m duplex. Figure 100 is a photograph of the northeast corner of the Boothbay Harbor Station. The major source of heat loss at this station is radiator leakage under the windows, an example of which is shown in Figure 101, a thermogram of the three second-deck windows on the left in the photograph. Figures 102 and 103 also show radiator leakage under the windows in addition to other artifacts, as was true for all four faces of the building. This could be easily rectified by station personnel, themselves, fabricating aluminum reflectors and installing them between the radiators and the inside walls. This was done successfully at Dartmouth College where thermographic detection of radiator heat loss through walls was first noticed.[6]

Figures 102 and 104 are thermograms of wooden garage overhead doors at Boothbay Harbor. It can be seen that the individual wooden panels lose as much heat as the glass window panes in the second row from the top of the doors. (The round object in these two thermograms is a spotlight.) Several of the other stations, such as the motor pools at New Castle, South Portland, and Southwest Harbor, exhibited the same kind of leakage through the wooden panels of the overhead garage doors. An overhead garage door found to

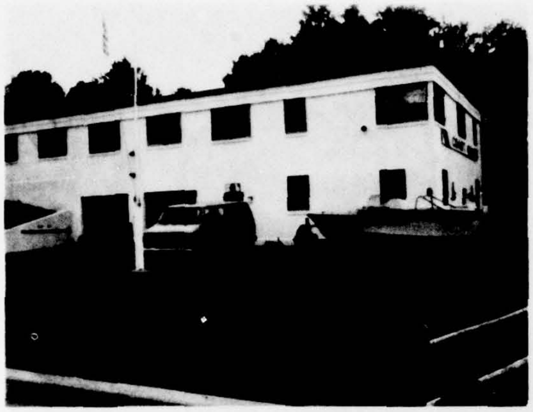

Figure 100. Northeast corner of Boothbay Harbor Station.

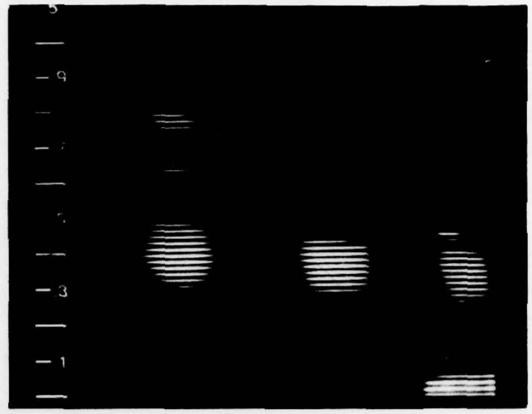

Figure 101. Radiator leakage under windows on east face.

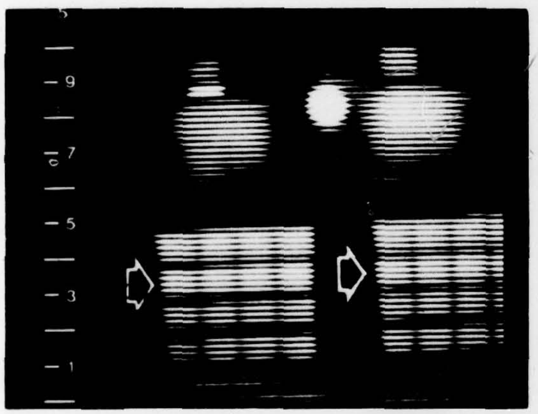

Figure 102. Wooden overhead garage doors with windows in them.

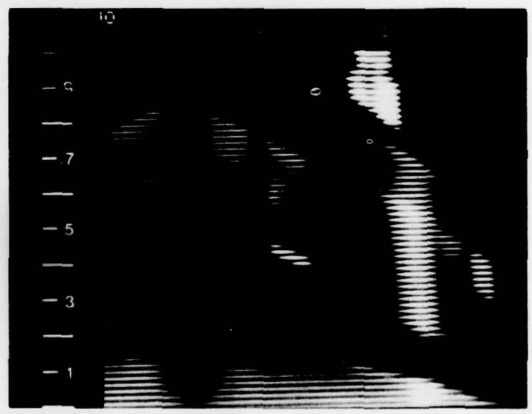

Figure 103. Vertical thermal pattern from chimney.

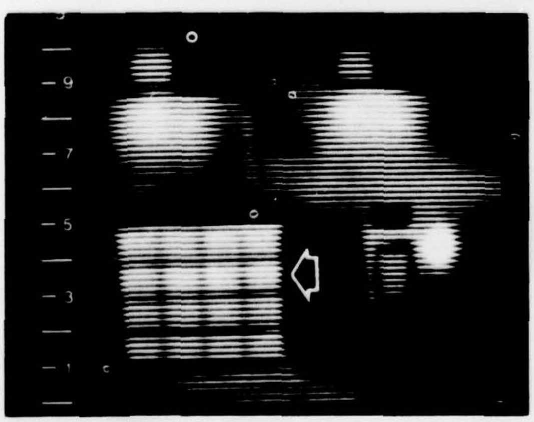

Figure 104. Leakage around door that is frequently used.

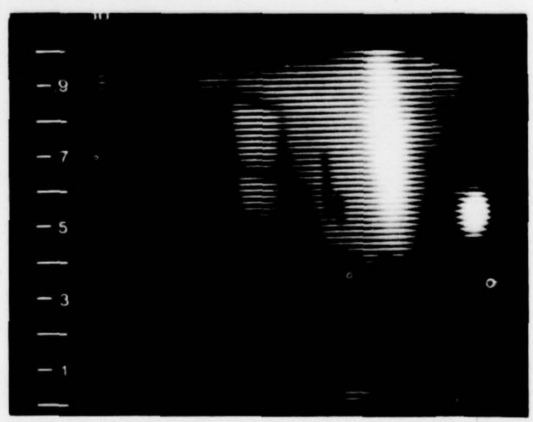

Figure 105. Vertical thermal pattern from chimney on north face of building.

Figure 106. Insulated fiberglass overhead door at New Hampshire Highway Garage.

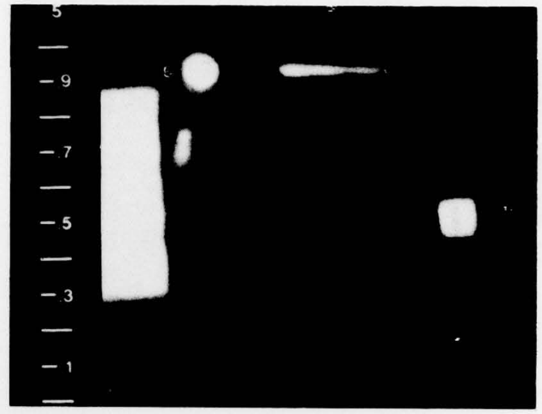

Figure 107. Thermogram of insulated fiberglass door.

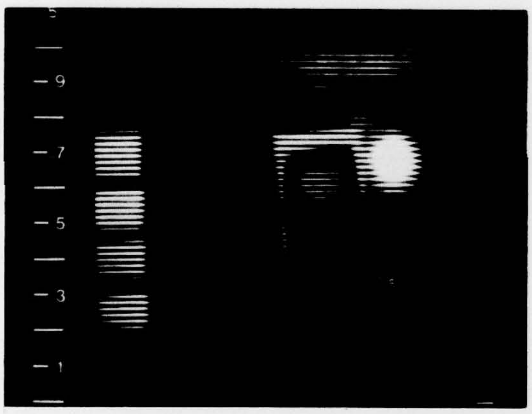

Figure 108. Closeup of overhead door and boat crew door on east face.

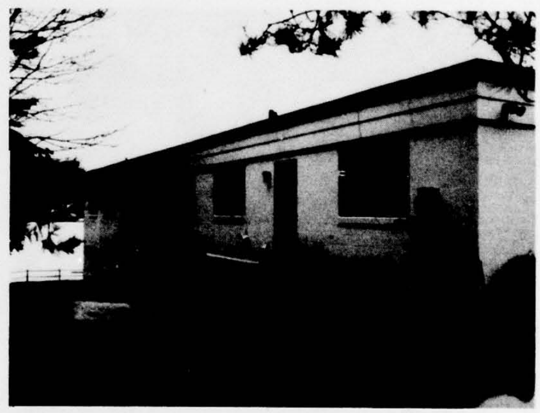

Figure 109. West face of Boothbay Harbor station.

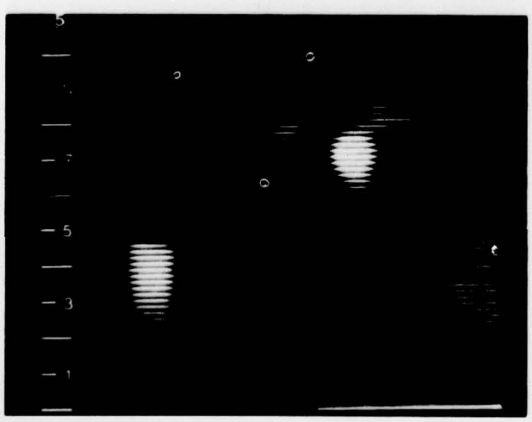

Figure 110. Rarely used galley door on west face.

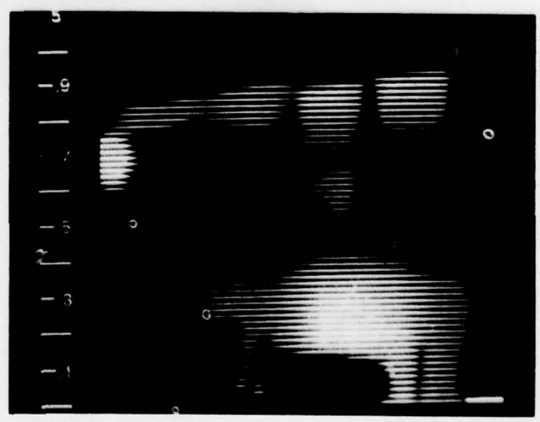

Figure 111. Radiator under window radiates through wall on west face.

be vastly superior to most was an insulated fiberglass door installed on the north face of the New Hampshire Highway Garage* in Concord, New Hampshire.[8] Figure 106 is a photograph of the door and Figure 107 is a thermogram of that door. This thermogram shows an almost completely black pattern, except for the small single window area and the top horizontal interface, which is probably due to the constant daily use that this door experiences. For orientation purposes, the white rectangular white area on the left of Figure 107 is the window on the left in Figure 106.

Figures 103 and 105 are thermograms of the north face of the Boothbay Harbor building showing the loss from the chimney. Figure 103 shows the second deck, and the darker area, through which the chimney thermal pattern passes, is the large wooden Coast Guard sign on the building wall. Most of the stations had external chimneys, and it would be logical to assume that valuable heat could be saved if future buildings were constructed with the chimneys in the middle of the buildings, as in older buildings. Perhaps stack heat reclaimers could be installed to reclaim some of this heat lost from the present chimneys.

Figure 108 is a closeup thermogram of the door to the right of the overhead garage doors in the east face. It shows the typical thermal pattern of a sprung door recognized and confirmed in Figure 78 and evident at a majority of the stations. This particular door gets very heavy usage as it is the passageway from the communications center to the boat dock used by the boat crews.

Figure 109 is the galley door on the west face of the building which is never used except as an emergency exit. Figures 110 and 111 show how tight and thermally sound the door is. Figure 110 also shows that the window immediately to the left of this door does not have a radiator pattern under it – only because there is no radiator under this galley window.

Southwest Harbor: Figures 112-124

The Southwest Harbor Base (Fig. 112) in Southwest Harbor, Maine, consists of a 32x12-m concrete masonry barracks with brick exterior, a 34x10-m concrete masonry administration building with brick exterior, a 15x10-m wooden supply building, a 12x11-m base exchange and several wooden duplex units. Figure 113 is a photograph of the north face of the new barracks building taken from the northeast corner. Closely adjacent private property and a thick row of trees prevented perpendicular shots, a problem sometimes encountered in ground survey work. The oblique angle thermograms still yielded valuable data. Figure 114 is a thermogram of the second deck windows to the left of the chimney, and Figure 115 the first deck windows under them. The radiators under the windows can be plainly seen. This is another one of the buildings that exhibited dark windows and warmer walls on all faces of the building. The north face was found to be warmer than the west face and a few of the windows were dark at the top panes and warm at the bottom panes, due either to frosted glass in the top panels or storms left in the top position. The third window from the right in

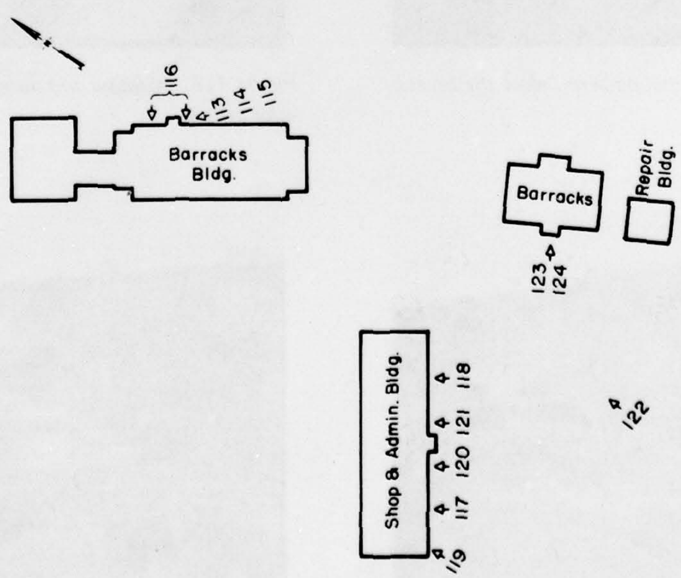

Figure 112. Southwest Harbor Base, Southwest Harbor, Maine.

* Though not part of this survey, the overhead garage door at Concord showed such insulating superiority that it is used as a reference standard.

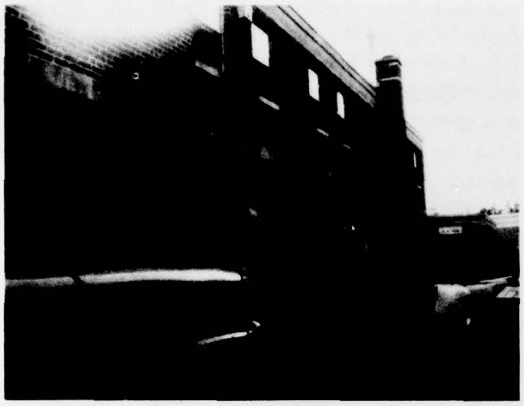

Figure 113. North face of new barracks at Southwest Harbor Base.

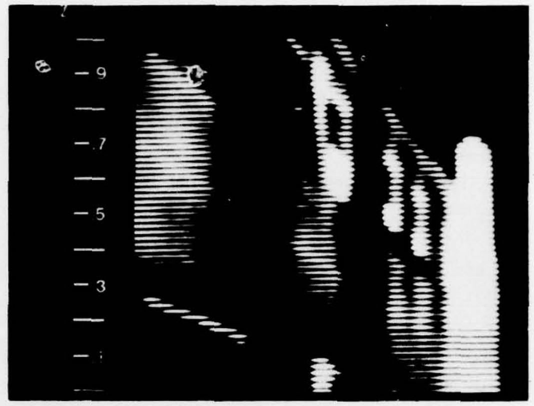

Figure 114. Radiator leakage under windows shows clearly on north face.

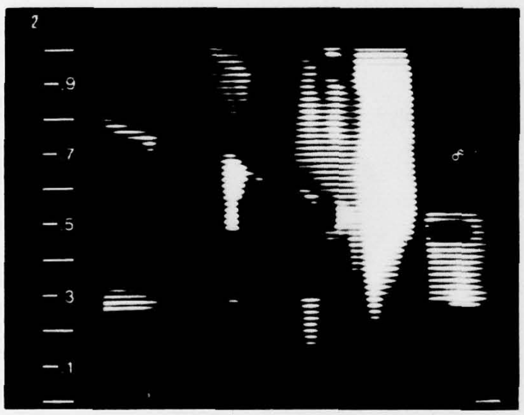

Figure 115. Cooler thermal pattern below the breeching on the chimney.

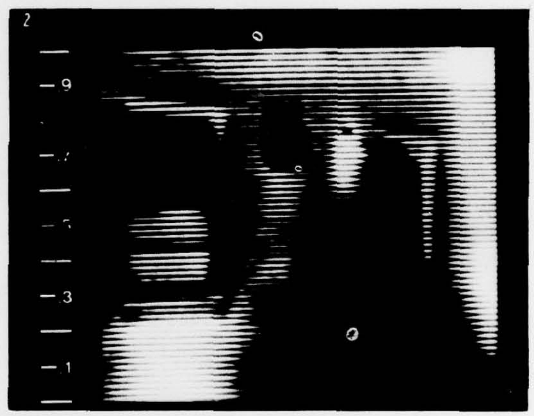

Figure 116. Window and door exfiltration leakage and solar effect.

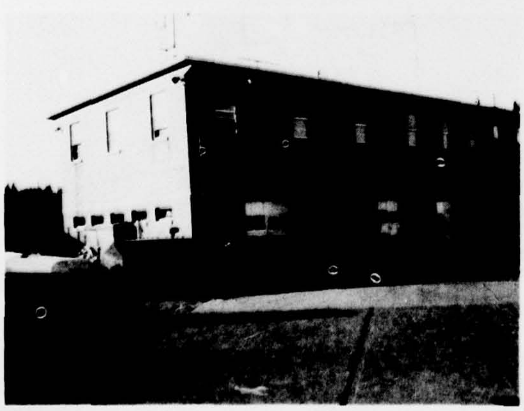

Figure 117. South section of east face of administration building.

Figure 118. North section of east face of the administration building.

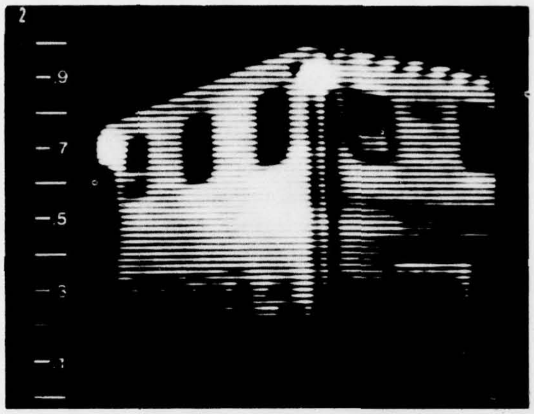

Figure 119. Apparent solar effect of cold windows and warm walls.

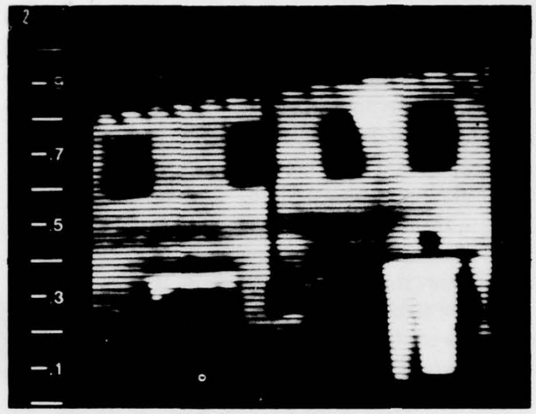

Figure 120. Excessive leakage from glass main entrance.

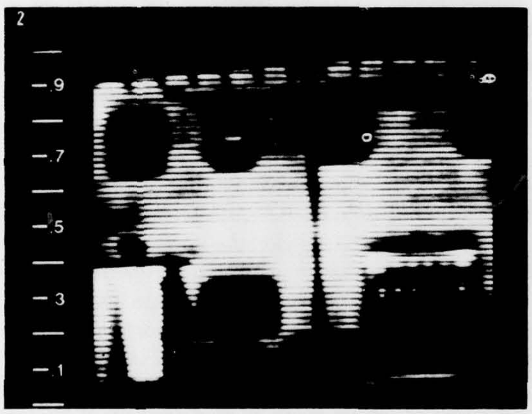

Figure 121. Leakage along top interface of garage door.

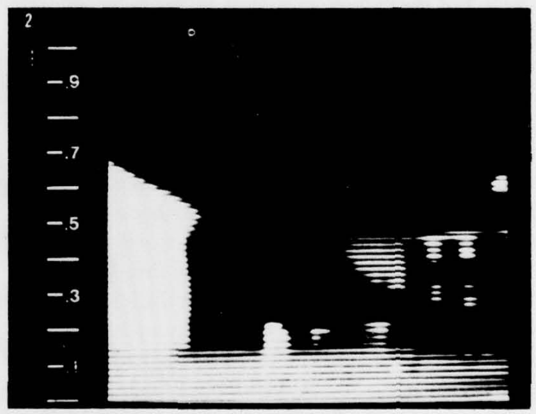

Figure 122. Brick building on left and wooden building on right.

Figure 123. Southwest corner of wooden building constructed in 1942.

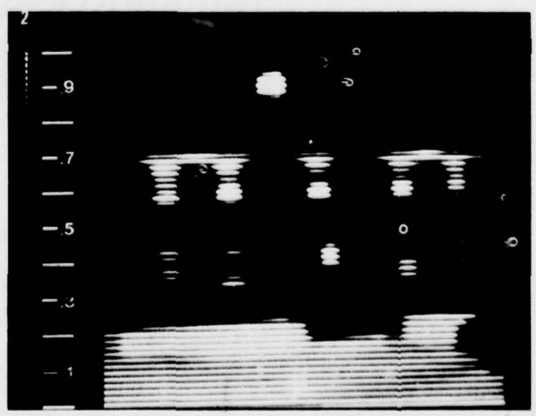

Figure 124. Thermogram of wooden building.

Figure 114 shows the warm wide area surrounding the dark center of the upper glass pane, indicating leakage between the wall/frame interface. Also, several of the windows clearly indicate leakage at the top horizontal wall/frame interface, proving once again that window leakage problems show up clearly in spite of the reversed thermographic pattern. The warm horizontal pattern of the second deck can also be made out in the warm radiator patterns, giving proof to the fact that the horizontal patterns are indeed heat from the concrete floor slabs and not from the small emissivity difference between brick and concrete (Table V). The very warm chimney is also evident, and Figure 115 shows the familiar cooler pattern below the breeching in the lower area of the ash cleanout door. The uniformly warmer east face of the galley can be seen in the lower right of Figure 115 and the small rectangular area is a sign.

Figure 116 is a closeup of the door immediately to the left of the chimney showing leakage around the top and upper right-hand portions of the door. The window to the left shows top horizontal interface leakage, and a dark upper glass panel and warmer lower glass panel. The radiator pattern under the window can be seen, as well as a rare example of lower horizontal window/wall interface leakage. This lower leakage does not normally show itself, presumably because the weight of the window units usually assures a better fit at the bottom interface. In addition, this illustrates that any vertical interface leakage at the left or right window/wall interface can best be discovered by viewing windows and doors at approximately 45° rather than perpendicularly. The cold closed vent can also be seen in Figure 116 and the white object in the upper left of the door is a spotlight.

Figure 117 is a photograph of the south section of the east face of the administration building and Figure 118 is a photograph of the north section of the east face. Figure 119, a thermogram of the southeast corner of this building, displays the solar effect of cold windows and uniformly warm walls. The south face on the left is at the same approximate temperature as the east face. The thermogram was taken at 2230 hours, which seems like a long time after sunset for the solar effects to remain, especially on a cold, windy night (Table II). The top horizontal leakage on the garage door can be noted and the window panes in the garage doors in this and the following two thermograms appear to be the same darkness as the window glass.

Figure 120 shows the leakage from the all-glass doors in the main entrance, but the all-metal double storage doors immediately to the left of the main entrance appear uniformly dark. The leakage above the other two garage doors is evident in Figures 120 and 121, and a few of the windows have small white areas indicating that the storm windows are left partially open all night.

Figure 122 is a thermogram that compares the temperature of the east face of the brick Administration Building with the south face of the wooden supply building. The brick building is much warmer and the wooden building does not display the solar thermal effects, indicating that wooden buildings cool off much more quickly than brick buildings.

Figure 123 is a photograph of the southwest corner of the wooden supply building, an old barracks built in the 1940's. The blueprints show 7.5 cm of blanket insulation in the stud bays and in the ceiling. Figure 124 is a thermogram of the south face and shows leakage typical of all the wooden buildings surveyed at the various stations. The foundation is very warm, and the warmth in the eaves indicates inadequate insulation in the attic. Numerous closeups of any portion of the stud bays show cool bays and warm studs, indicating that insulation is present. It can also be seen that the warm chimney is at the center of the building, the radiators do not show through the walls, and the front entrance has an enclosed vestibule. These features show that architects in the 40's were more committed to energy conservation in buildings than many seem to be today.

Jonesport: Figures 125-137

Jonesport Station (Fig. 125) in Jonesport, Maine, consists of a 44 x 12-m concrete masonry barracks with

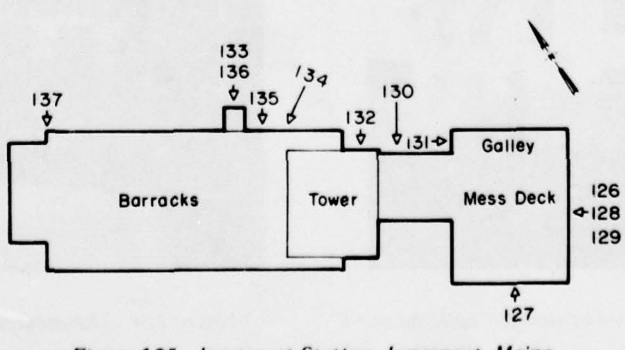

Figure 125. Jonesport Station, Jonesport, Maine.

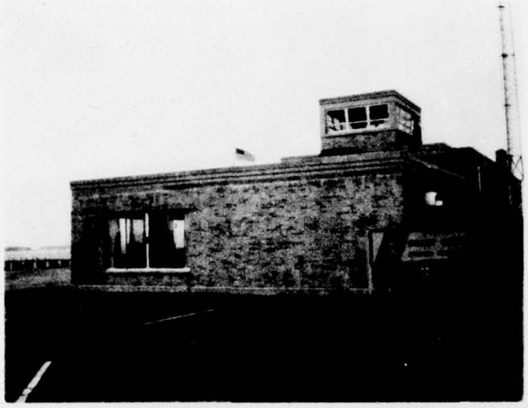

Figure 126. East face of mess deck and galley at Jonesport station.

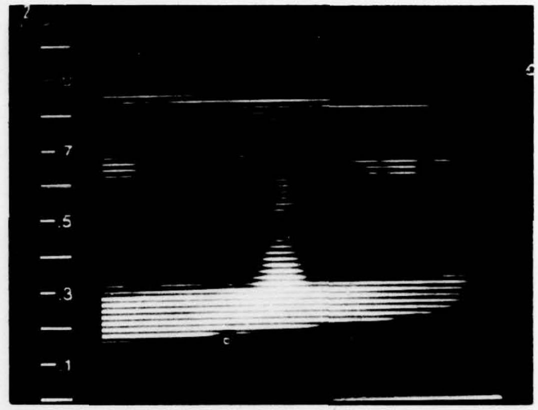

Figure 127. Mess deck windows on south face.

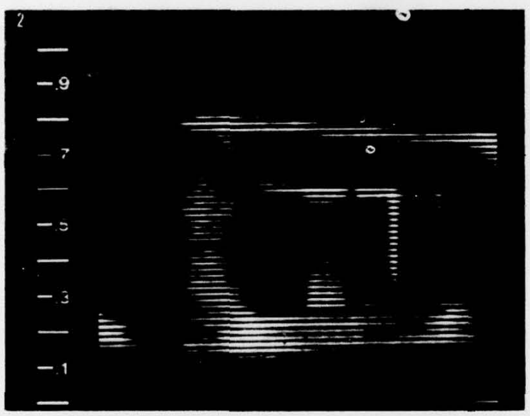

Figure 128. Badly sprung window unit on east face of mess deck.

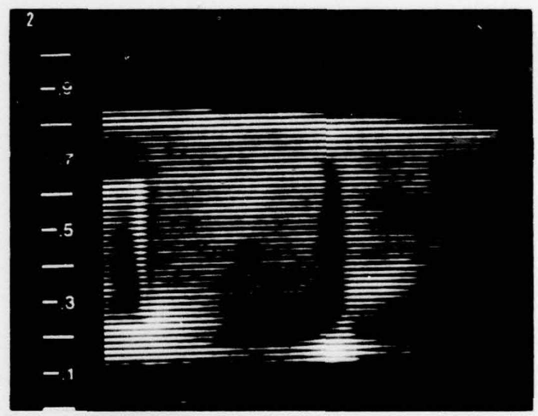

Figure 129. Cool foundation on east face of mess deck.

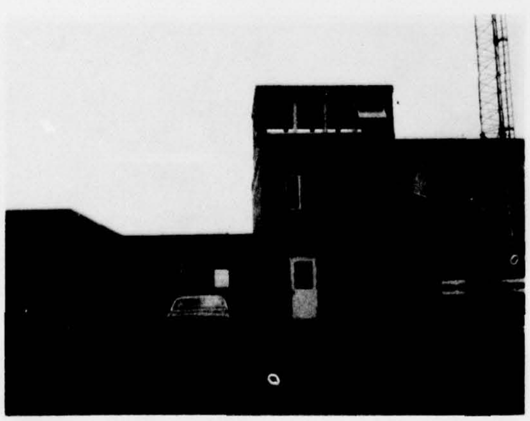

Figure 130. North face of galley and two-deck barracks section.

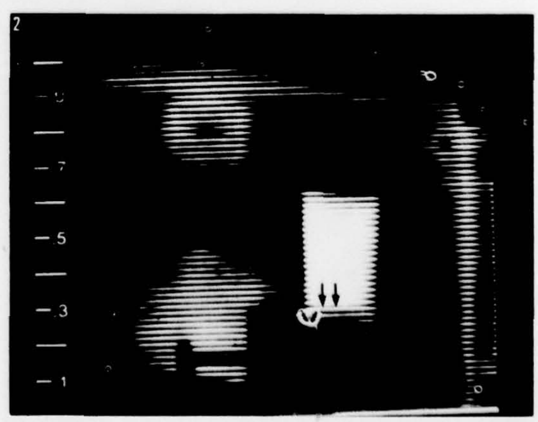

Figure 131. Galley door on the northwest face.

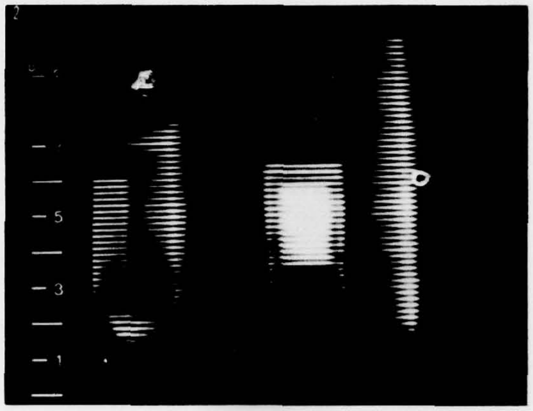

Figure 132. Leakage on north face.

Figure 133. West section of the north face of barracks section.

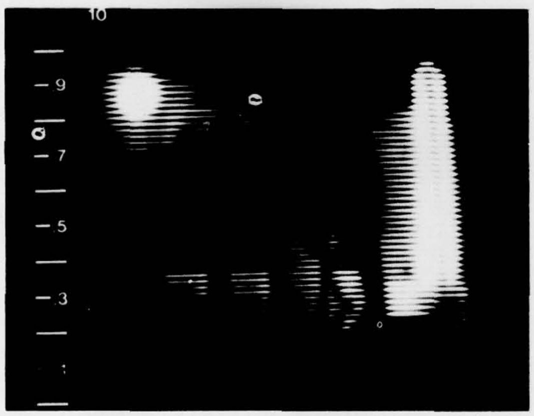

Figure 134. Chimney that is warmer than glass window transoms.

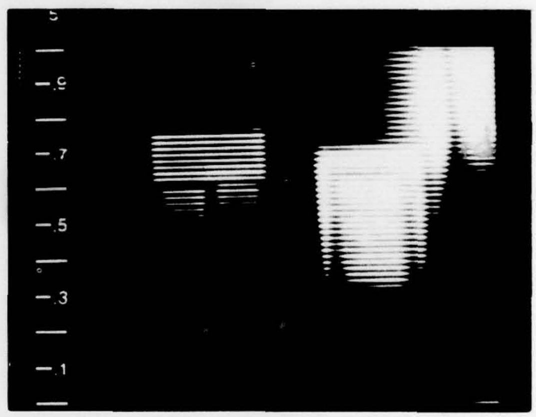

Figure 135. Exfiltration around upper half of door.

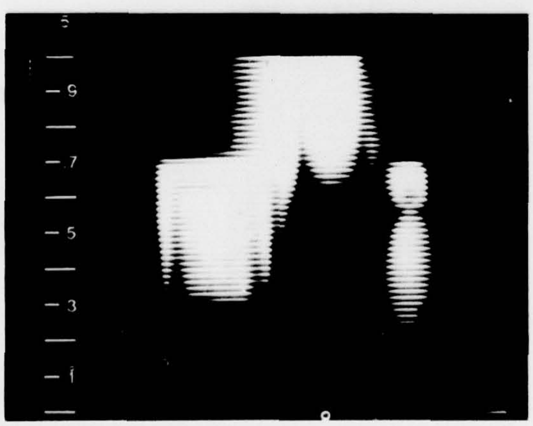

Figure 136. Plume of warm air from vent to right of chimney.

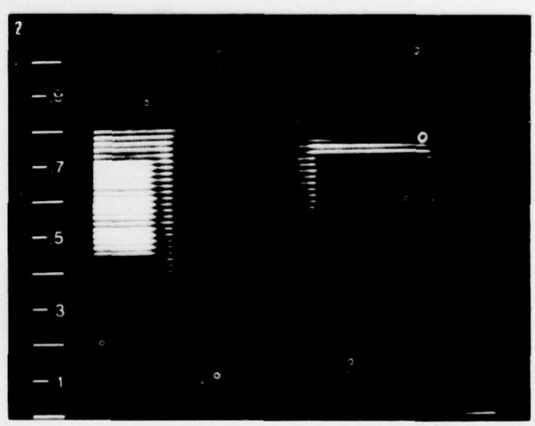

Figure 137. Paint storage locker doors losing heat.

brick exterior built in 1969, a 15 x 10-m wooden duplex, a motor pool with brick exterior, a heated boathouse with brick exterior, and several single-story housing units. Figure 126 is a photograph of the east face of the Jonesport Station mess deck and Figure 127 is a thermogram of the south face windows of the mess deck. These windows are of the horizontally sliding aluminum type, and they exhibit leakage along the vertical meeting rails and along the top horizontal interface. Figure 128 is a thermogram of the window unit on the east face of the mess deck which was sprung by the wind and which leaks quite badly whenever there is wind-driven rain from this direction. The thermogram of this window in Figure 128 shows that the first vertical meeting rail from the right is in poor condition and the top horizontal interface leaks badly.

Figure 129 is a thermogram of the wall to the right of this window, which shows (along with Fig. 128) that the floor slab at this station is cooler than the wall – the opposite of conditions at most of the stations. The dark vertical stripe shown in Figure 129 is a cavity containing pipes to the dishwasher in the galley.

Figure 130 is a photograph of the north face of the galley, the connecting section, and the east section of the two-deck barracks. Figure 131 is a closeup thermogram of the galley door located in the northwest section of the galley. In addition to the noticeable leakage through the glass panel in the door, the vertical ribs in the lower portion of the doors can be seen (small arrows). The upper left-hand pattern is a vent, the metal portion of which is cool but the area around it is warm. The warm pattern in the lower left wall area is coming from a small locked room to the left of the door that contains a freezer. The warm vertical construction joint interface with the connecting section can be seen at the right-hand edge of the thermogram.

Figure 132 is a closeup thermogram of the east section of the north face of the two-deck barracks section shown in Figure 130. It shows the vertical construction joint interfaces between the connecting section and the tower stairwell, and between the tower stairwell and the two deck barracks section. Notice that the vertical construction joint to the right of the door shows a warm, wide pattern radiating out to the left on the brick wall towards the door. The door itself shows leakage along the top and side interfaces.

Figure 133 is a photograph of the west section of the north face of the two-story barracks. Figures 134, 135, 136 and 137 are thermograms of selected portions of this north face which do not exhibit the familiar radiator leakage under the windows. All the windows are closed, demonstrating that this station has six heating zones each separately controlled and comfortably regulating the internal temperatures. Leakage from the glass transoms above every window (Fig. 134 and 135) is unnecessary, however, and the transoms could be replaced with insulated panels similar to those shown in Figures 88-90.

Figure 135 shows a closeup thermogram of the leakage around the door to the left of the warm chimney and Figure 136 shows the plume of warm air emanating downwards from the vent to the right of the chimney. Figure 135 also shows the glass transom and the top portions of the two glass panels which appear much warmer than the lower portions of the window unit. This again emphasizes that the tops of the window openings lose the most heat and therefore that top insulated panels are a valuable energy conservation measure.

Figure 137 is a thermogram of the west door in the north face, together with the metal door to the paint locker to the right of it. The paint locker door leaks badly at the top and side interfaces. Perhaps this door could be covered with plastic or sealed in some other way to reduce losses during the wintertime.

CONCLUSIONS

The main conclusion of this report is that brief but thorough IRTB surveys can produce a great deal of information about the thermal efficiency of buildings if the survey process is optimized by accurate planning, complete surveying of all surfaces, and painstaking thermogram interpretation. Careful planning should involve the individual who will actually do the survey, and the survey specifications should incorporate input from the occupants of the buildings to be studied. The thermographer should also do the post-survey interpretation, because of his familiarity with the IRTB data.

The chief equipment problem encountered in this survey was the malfunctioning of the Polaroid camera used to record the thermograms. The problems with the Polaroid camera were overcome by keeping the film warm, using coaterless film, cleaning the rollers after removal of each film pack, and keeping the camera inside except when actually shooting. It was discovered that rain does not hinder the infrared imagery but that it does soften the Polaroid film tabs, and the thermographer must take all eight shots quickly or lose part of the film pack.

It was found that the infrared system performs well in the field under harsh conditions with only minor operating problems, and can be left outside during a survey. However, the image splitter in the Polaroid camera is very fragile and improper replacement causes double images. The greatest inconvenience of the system is the constant need to keep the batteries charged

and to conserve power by turning the system off whenever one is attending to the thermograms and other data. Locating sources of liquid nitrogen in the field can also cause inconvenience.

Split-ribbed blocks, staggered blocks, stacked concrete masonry units filled with insulation and old brick buildings at 10 different sites were surveyed. All showed examples of missing, settling or inadequate insulation, entrapped moisture, warm spots, or other problems. Many foundations and slabs were found to be warm, and different building faces had differing temperatures. Solar effects, while causing a uniform warm building face, were found to actually improve thermography of window and door openings by increasing thermal contrast.

Windows and doors were examined in detail. Many were found to be badly sprung by the wind and several were found to leak during rain. Thermographic comparisons of new windows and original windows dramatically illustrated the simple fact that windows and storm sashes must be kept shut in order for the new windows to be energy effective. Windows were found to infiltrate along their bottom interfaces and exfiltrate along their top interfaces.

Architectural design inadequacies for cold regions were numerous and clearly pointed out by thermography. Glass doors, glass transoms over windows, and main entrances without vestibules are examples. Single zone buildings were found to cause occupants to waste heat by leaving windows open all winter. New buildings with outside chimneys lost usable heat that was conserved in older buildings with inner chimneys. The placement of windows in unoccupied rooms, such as lockers and boiler rooms, was another poor design feature discovered by thermography.

Selecting qualitative standards and using them as a example against which normal or subnormal building components could be judged in a survey was found to be a useful concept. Thermograms of an unused door, a fiberglass overhead garage door, and an insulated porcelain window panel were selected.

The 120 thermograms and photographs selected for this report illustrate most of the anomalies discovered during this Coast Guard survey of 26 buildings. They can serve as a "thermographic dictionary" illustrating typical anomalies to be found in thermographic surveys of brick and block buildings.

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